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# Army Battlefield Environment

Volume 12, Number 4 Spring 1998

Researchers at the Army's VETRONICS Laboratory are designing soldier-machine interfaces, which will enhance the Force XXI effort to revolutionize the way military operations are waged in the 21st century. (Story on Page 1.)

## *ALSO IN THIS ISSUE . . .*

*The effects of "X" class solar flares on Army operations, such as GPS*

*IMETS weather digitization provides significant support to Force XXI*

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| **Abstract** The U.S. Army is embarking on an effort to revoluntionize the way war is waged in the 21st century. This effort, dubbed Force XXI, is the vision to synthesize the technology, doctrine, and organization of the U.S. Army. Three key facets are: 1) The use of electro-optic sensors to supplement direct vision to increase fightability at night, in adverse weather conditions, and to extend the engagement range of weapon systems; 2) The transmission of messages on the battlefield digitally, instead of via voice radio; and 3) A real-time data base that tracks the location of all friendly systems, as well as enemy systems, decreasing friendly fire kills and improving the commander’s decision making ability. | |
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# MODELING AND SIMULATION

## Usable interface for weapon systems will enhance Force XXI effort

**by Dr. Susanta P. Sarkar**

Designing the user interface for real-time multi-user weapon systems is a challenge for two conflicting requirements. First, the dialogues must be powerful to accomplish operation with minimal interaction - i.e. task-oriented interface design. Second, the user must be able to access and be aware of all aspects of the relevant systems - i.e. system-oriented interface design. These requirements are further complicated by more than one simultaneous user and having a dialogue space influenced by previous actions of other users.

In the VETRONICS Laboratory of the U.S. Army, this challenge is tackled by following a unique process for designing soldier-machine interface. Results of simulation shows that the developed design through this process provides adequate usability.

### Introduction

The U.S. Army is embarking on an effort to revolutionize the way war is waged in the 21st century. This effort, dubbed Force XXI, is the vision to synthesize the technology, doctrine, and organization of the U.S. Army. Three key facets are: 1) The use of electro-optic sensors to supplement direct vision to increase fightability at night, in adverse weather conditions, and to extend the engagement range of weapon systems; 2) The transmission of messages on the battlefield digitally, instead of via voice radio; and 3) A real-time data base that tracks the location of all friendly systems, as well as enemy systems, decreasing friendly fire kills and improving the commander's decision making ability.

A user interface for an Army ground combat vehicle optimized for the digitized battlefield is described in this article. This user interface was developed as part of the Crewman's Associate program [1,2]. Crewman's Associate is one of the U.S. Army's Advanced Technology Demonstrators (ATD). ATDs are part of the Army's Science and Technology Master Plan. An ATD is a risk-reducing "Proof of Principle" demonstration conducted with heavy soldier/user involvement, culminating in a constructive, virtual, or live experiment.

This article is organized as follows: Immediately following this introduction, a *Background* section explains why a new user interface is required. *Requirements for User Interface* follow. The next section is a description of the *User Interface Design Process*. *The User Interface Design* is described in the following section. The next section is dedicated to describing the *Evaluation* process. Finally, a *Conclusion* is offered to summarize the article.

### Background

Digitization of the battlefield will affect the warfighter at every echelon. "Operationally, digitization will provide enhanced situational awareness with friendly and enemy tracking; a common battlefield view; fratricide reduction; self-location and navigation; horizontal information exchange; target hand-over; and facilitation of force synchronization."[1]

"Much of the emphasis to date in the digitization initiative has focused on the hardware and software required to support it. However, of equal, if not more importance is the effective integration of the digital subsystem(s) with the soldiers who will operate and maintain it. Failure to address soldier-system integration issues early in the digitization program will result in suboptimal or even negative effects in operations and/or maintenance of the systems being 'digitized.'"[2] This effort directly addresses this concern.

Also, many of the digitization efforts to date have only addressed the requirements of the upper echelon commanders. In contrast, this effort specifically supports lower-echelon requirements, the combat crewmen that are directly responsible for putting "steel on steel."

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[1] Maj. Gen. Joe W. Rigby, "Acquiring the Digitized Force," *Army RD&A Bulletin*, (November-December 1994), 14-15

[2] Maj. Gen. Wallace C. Arnold, "MANPRINT and the Digitized Battlefield," *Army RD&A Bulletin*, (November-December 1994), 39-41

### Requirements for user interface

3.1. Multiple Users

Normally, a user-interface designer is concerned with one user at a time. However, combat vehicles are operated by multiple users. Each user operates different aspects of the vehicle. The effectiveness of the combat vehicle depends on the coordination of the activities of the crew. To illustrate this concept, take the example of a situation where the crew is trying to destroy a target. The crewman that is in command of the combat vehicle, the commander, finds the target, and determines whether it is friendly or not and is responsible for the actions of the entire crew. The crewman that controls the gun, the gunner, aims and fires the gun at the target upon direction from the commander. The challenge for the user-interface designer is to design such an interface so that hierarchy of command among the users is built into the design, while maintaining similarity of interface design among the users.

The other major consideration in the design is that the current dialogue space of one user could be influenced by previous actions of the other users. Considering the previous example, if the commander has decided that the current target is not an enemy, the gunner should not fire at this target. Thus, there are some actions which have dynamic preconditions for correct operation.

3.2. Intended for Real-Time Weapon Systems

In the context of weapon systems, activities of enemy forces demand appropriate timely actions. The consequence of not meeting a deadline is severe. One of the obstacles in meeting this deadline is the delay in formulating and reaching the appropriate action. Thus, the user interface must provide means of speedy access to safety-critical functions. Also, at all times the critical options should be reached with very few actions (button press or menu traversing). Thus, all the major functional areas applicable for a crew must be available at all times or be reachable with minimal actions. For example, the commander should be able to access the Command and Control functions at all times when he is working deep in the target acquisition menu.

3.3. Criticality

The margin for error is minimal in combat vehicles, and the results can be catastrophic. At stake is loss of life of an individual crewman, of the entire crew of a combat vehicle, of all the combat vehicles in the unit (platoon, company, battalion, etc.) and ultimately danger to a nation's security. Conventional means of correcting mistakes are not available due to real-time constraints. Also, a dialogue box for confirmation cannot be used because of real-time constraints. So, the user interface must be designed so that the probability of incorrect actions by the crewmen is minimized.

3.4. Motion

Combat vehicles operate under extremely harsh conditions. One condition in particular, which affects the crewmen's ability to interact with the user interface is motion. Combat vehicles travel at speeds up to 40 miles per hour cross-country; not on paved roads, frequently not even on roads. The result is extreme oscillations, vibrations and G-forces. The user interface must take into account this condition in which it will be operated.

3.5. Task-Oriented vs. System-Oriented

There are two distinctly different models for Machine-Human Interface: the Engineering model and the User-task model [3]. In the Engineering model, access to the system is provided through the interface, whereas in the User-task model, only interface to accomplish tasks are provided. The requirement of powerful dialogue argues for User-task model for combat vehicles. It is true that when the crews of the combat vehicle are very busy dealing with immediate danger, the task-based model provides the maximum effectiveness, but the same system is supposed to provide diagnostic messages about its health when hit during a battle, so that the user could adjust his action. Thus, there are some activities that require engineering model of user interface. In order to achieve our objective, a hybrid of both the models are used. The user interface is primarily task-based, but at certain levels access to the system is provided.

3.6. Space Constraints

Rapid deployment of combat forces requires air transportation. The weight and volume of the combat vehicle is the limiting factor in air transportation, so these factors must be minimized to facilitate rapid deployment.

Survivability is inversely proportional to vehicle height. The ability to be seen on the battlefield, by enemy forces, is directly proportional to vehicle height. Also, the probability of being hit by enemy armaments is height dependent. Thus, minimizing the profile of combat vehicles is an important objective.

Thus, the available surface area and volume available for interface design is severely restricted.

3.7. Introduction of Multimedia

In previous designs, the user's visual, motor, aural and voice channels are heavily used. Due to ready availability and basing new design from earlier tested

designs, visual channels act as input to the user where as motor and voice channels are primarily for output. Advent of three-dimensional audio leads us to use this channel for direction sensitive cueing. In case of imminent danger, a directional aural cue is provided to the user so that he could aim his visual channel to take appropriate action.

## User-Interface design process

### 4.1. Overview of the Design Process

The crew station designed in this effort takes into account more than the traditional user-interface design. The design followed the following process:

- Identify interface objectives and requirements.
- Perform a task analysis.
- Determine crew station geometry.
- Locate controls and displays.
- Identify design principles.
- Preliminary design
- Detailed design
- Simulation
- Redesign

### 4.2. Objectives and Requirements

A combat vehicle is an extremely complex system that operates in a wide variety of environments. It has four primary requirements: 1) Move, 2) Shoot, 3) Communicate and 4) Survive. Major crew tasks were identified from the functional descriptions of the subsystems. Detailed interface requirements were derived from the Army Field Manuals, Operational Requirements Documents, and interviewing and working with combat vehicle crewmen.

In addition, the following specific desirable attributes of the interface were identified:

- Decrease task execution timelines.
- Improve operations on the move.
- An intuitive and easy to learn interface to the Force XXI.
- Improve night operations.
- Reduce maneuver damage.
- Improve continuous operations.

### 4.3. Task Analysis

For the combat vehicle, a list of critical tasks and their frequency and duration were prepared. This list was prepared from a combination of information: Validated task analysis of existing vehicles in use, subsystem experts, and technology experts. Using this task information, a detailed task analysis of the combat vehicle was performed.

A task analysis is the foundation of an interface design. With most task analyses, the importance of tasks is derived from their frequency of use, leading to higher usability. In a combat vehicle, however, real-time requirements and mission criticality of the function are factors that are given more priority than frequency of use. Based on this criticality, three modes were identified starting with the highest critical level: 1) Engagement during combat, 2) Combat, and 3) Noncombat. A vehicle is in noncombat situations most often. It is in combat situations much less often, and engagements are a small subset of combat situations. Although the frequency of the noncombat functions are much greater, their criticality and real-time requirements are less. Hence, they are not given priority treatment in the user-interface design.

Frequency is then used to sort the functions within each mode.

### 4.4. Design Principles

Listed below are four of the key principles used in this effort.

#### 4.4.1. Hands-on Primary Controller

The crewman's hands should stay on his primary controller, while executing critical tasks. Critical tasks are defined as those that must be performed during combat, while in contact with the enemy. Adhering to this principle provides two benefits:

- Reduced task execution timelines
- Decreased fatigue

#### 4.4.2. All Critical Information in the Primary Vision Zone

All critical visual information should be in the primary vision zone. Critical visual information is defined as information that the crewman needs to see while in contact with the enemy. The primary vision zone is the area that can be seen by a crewman without any head movements; simply with eye pupil movements. As with the first design principle, two benefits accrue when all critical information is displayed in the primary vision zone:

- Reduced task execution timeline
- Decreased fatigue

#### 4.4.3. One Step Functions

In the combat system of the digitized battlefield, there will be a much greater degree of electronic integration. Functions that currently are mechanically actuated will be electronically actuated. This makes it possible to base the user-interface design more on the crewman's needs than on mechanical constraints. For

example, assume the crewman needs to accomplish Function A, consisting of performing four sequential tasks. In a mechanically integrated system, the crewman needs to perform the function in four separate steps, each requiring a separate actuation. In an electronically integrated crew station, it is possible to group all the separate tasks that must be performed for Function A, and execute them following a single actuation by the crewman.

4.4.4. Consistent Mental Model

It is important that the soldier-machine interface design be controlled by a single entity to ensure a consistent interface is presented to the crewmen. The crewmen must be presented with one consistent interface to all the subsystems; it should be transparent to the crewman that he is actually interfacing with multiple subsystems. The way he interfaces with one subsystem must be identical to the way he interfaces with the other subsystems. The user learns how to perform a function once, and then does it the same way across all applications.

4.5. Crew Station Layout

Layout is another characteristic that makes the design of this user interface unique. For most user-interface designs, the layout is well established: A video display terminal on a desktop, with a keyboard and cursor control device in front. The space available for the user is unlimited. In combat vehicles, however, the space allotted for the user is tightly restricted, and getting smaller as the push is made for lower profile vehicles. Thus, the layout of the crew station is a key part of the design process.

*The Process*: First, the exact envelope of available space is determined. Next, a *Seat Reference Point* is determined. The seat back angle is 30 degrees, which is optimal for high vibration environments.

Next, *the Design Eye Point* is identified. Note that the user interface must support fifth to 95th percentile male users; thus adjustability of the seat is a key issue.

Finally, the displays and controls are located and oriented, taking into account the aforementioned design principles. The crew station layout is done in parallel with the task analysis, although a link is required between the two efforts because the task analysis will impact the number of displays and controls required.

4.6. Preliminary Design

The Preliminary Design Phase included entering the entire crew station into a Computer-Aided Design package with displays and controls. The video and auditory displays were selected based on system requirements. Finally, a screen layout for the video displays were designed.

4.7. Detailed Design

The detailed design phase was based on the task analysis. In this phase, the specific controls were selected or designed. Designing the custom controls was an extremely important part of the design.

Next, the information to be presented on the video and audio displays were detailed. This includes the design of every screen, and what and how information would be specifically presented auditorily. An iterative design approach was used. This meant mocking the screens up, and having users provide feedback and guidance during informal User Juries.

The iterative approach is very time-consuming. But, it greatly increases the probability of "getting it right the first time." Also, the time required to use the iterative approach has greatly decreased due to the availability of rapid prototyping.

The final part of the Detailed Design Phase was *emulating the design in a high-fidelity* man-in-the-loop crew station simulator, and then holding informal User Juries. This is a unique part of the design process. While traditional review of screen designs is common, it only allows the user to review the aspects of the design in isolation, and under benign conditions. Full man-in-the-loop virtual simulations allowed the users to experience the complete *system* design, while under simulated battlefield conditions. At this point, a large number of comments and recommendations, not previously provided during the rapid prototyping phase, were contributed. This highlighted the value of full system simulation during the design process.

## User-interface design

The first part of section 5.1, discusses the user interface in a macro sense; the layout of the crew station. Section 5.2 discusses the design principles in a specific vehicle subsystem used in the user interface.

*5.1. Crew Station Overview*

Figure 1, (See Page 5.) graphically depicts the ground-combat vehicle crew station optimized for the digitized battlefield. The following is a description of this crew station.

5.1.1. Panoramic Display

At the top is an electro-optic panoramic display. An electro-optic display system is needed in a vehicle configuration where adequate direct optics vision is unavailable. The panoramic display is located such that it adheres to the design principle, *All Critical Information in the Primary Vision Zone*. This decreases task

**Figure 1. Ground combat vehicle crew station**

execution timelines and minimizes physical and cognitive fatigue.

5.1.2. Multifunction Displays

Located directly below the panoramic display are three multifunction displays (MFDs). "Multifunction" means that the displays are not dedicated; they can be set up by the crewman to display information from, or the status of, a number of different subsystems. The push buttons along the top row of the MFD allow the crewman to select between the system screens listed above. There are Programmable Display Push (PDPs) buttons along the left and right sides of the MFD. PDPs have integrated displays driven by external input sources, and thus, can be customized for each application. These PDPs provide access to the functions associated with each system.

As with the panoramic display, the MFDs are located in the crewman's *Primary Vision Zone*. Also, note that by using identical displays and identical push buttons, and by avoiding dedicated interface hardware, a *Consistent Mental Model* can be presented to the crewmen.

5.1.3. Hand Controller

Centrally located below the MFDs, is the primary controller, a two-handed yoke. This yoke, (Figure 2, Page 6.) is a critical component of the user interface. Its design is both unique and important for two reasons.

First, it allows critical functions to be performed from a single user interface. This yoke allows one crewman to perform the functions of gunner, driver, commander, and loader, all from the same user interface.

Second, this yoke makes it possible to realize one of our key design principles: *Hands-on primary controller*. The functions that must be controlled during critical periods of combat are accessible to the crewman without his hands leaving his primary controller, thus, reducing task-execution timelines, and decreasing fatigue over continuous operations.

Near the bottom of the controller are lighted push buttons that allow the crewman to select his primary function. At the left is a steering wheel icon. When this is depressed, the user interface is configured for driving. The acceleration and braking foot pedals are activated. The yoke is locked out in the fore/aft direction so that the driver can brace himself over rough terrain. The

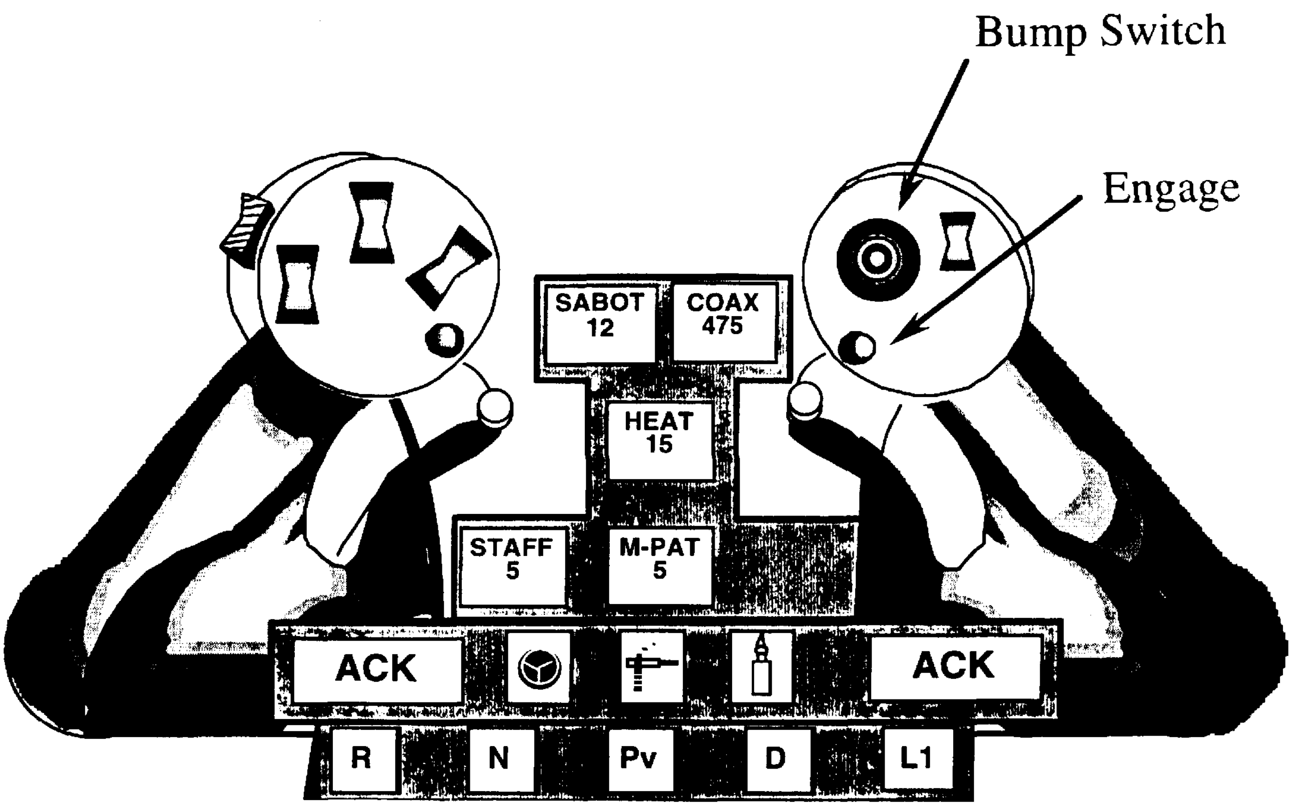


**Figure 2. Primary controller**

left-right movement is used for steering. On the horizontal axis directly below the steering wheel icon are the transmission gear-select switches: Reverse (R), Neutral (N), Pivot (Pv), Drive (D), and Low (L1).

At the right is an icon of a SABOT round. When this is depressed, the crewman has control of the target acquisition sensor and the main gun. The foot pedals are not active. The yoke is now used to direct the target acquisition sensor. The fore/aft movement controls elevation, and the left/right movement controls azimuth. On the center pod are the ammunition select push buttons. Each push button also displays the round inventory, which automatically decrements as rounds are used. On the left grip are switches used for control of the sensor. On the right grip are switches used to control engagements, and a bump switch used to interface with the MFDs.

It is important to note that the design of the controller is based on a thorough task analysis. All the tasks that must be performed from the user interface were identified. Also, the frequency with which each task is performed, and when (combat, post-combat, etc.) was analyzed. The results generated this yoke design. The crewman's hands do not have to leave this controller during combat, specifically during enemy contact, thus, decreasing task execution timelines.

Further use of the task analysis, combined with the design of the yoke, allows adherence to another design principle: *One Step Functions*. To illustrate the application of this principle, an example is cited: A potential target has been recognized. Before the trigger can be pulled, the following tasks must be accomplished: 1) arm gun, 2) lase for range, 3) combat identification query, 4) change to narrow field-of-view for visual target identification, 5) engage autotracker, and 6) link gun with the independent targeting sensors line of sight. With a single actuation, the depression of the Engage button on the yoke (See Figure 2.), all the tasks are performed. Six crewman actions have been reduced to one crewman action, reducing the engagement timeline accordingly.

5.1.4. Three-Dimensional Audio System

While analyzing the crew work load of current weapon systems, we determined that the visual, physical and cognitive channels can become overloaded. We decided, therefore, to make greater use of the auditory channel. To facilitate this, the user interface has a three-dimensional (3-D) audio system. In a 3-D audio system, the audio information is presented to the crewmen via their headphones. The 3-D audio system modifies the information presented to each ear in such a manner that a perceivable and distinguishable spatial context is added. Twelve different horizontal positions around

each crewman are presented. Also, the system supports displaying information with a vertical component.

Via the 3-D audio system, each crewman receives information from: 1) two radios (Radio A and Radio B), 2) the intercom, 3) the system (warnings, alerts, cautions, and advisories), and 4) the integrated defense system. All audio information is presented based on each crewman's head position, using a head-tracking system. If the head-tracking system fails, the 3-D audio system reverts to predefined defaults based on the head facing forward.

Radio A is spatially presented over the crewman's left shoulder. Radio B is presented over the crewman's right shoulder. The intercom audio will appear to emanate from the other crewman's position. The warnings, alerts, cautions and advisories provided by the system will be at 1200 clock position. Warnings from the integrated defense system will be provided along the line-of-bearing of the incoming munition. By providing the line-of-bearing audibly and instantaneously, the crewman will be able to immediately effect a countermeasure, saving the .25 - .5 seconds lost if the crewman is required to rely on a visual display.

5.1.5 Objectives Met

It is important to note that key user-interface objectives were met in the design of this crew station. The interface supports multiple simultaneous users. It is optimized to support critical decision making in real-time situations. Also, it supports a user operating the system, while experiencing motion due to the vehicles movements.

5.2. Digital Command and Control System

The first part of this section gave a top-level description of the user interface. This section provides a short, low-level view of the user interface to a particular subsystem, the digital Command and Control ($C^2$) system. The $C^2$ system is one of the critical elements of the digitized battlefield. First, the requirements of the digital $C^2$ system will be identified. Next, the design principles for the $C^2$ system will be listed. A detailed account of the *entire* user-interface design is available in a document titled "Advance Abrams Crew Station Design Document," (www.tacom.army.mil/csd/ca_index.htm).

5.2.1. Requirements

The interface described in this section meets the requirements defined in the following documents:

- "Operational Requirements Document for Force XXI Battle Command Brigade and Below," July 1, 1994;
- "Force XXI Battle Command User Functional Description," July 1, 1994; and
- "Variable Message Format Technical Interface Design Plan," Volumes I, II and III, July 31, 1995.

5.2.2. Design Principles

The design of user interface being described in this article was guided by the use of the human factors design principles cited earlier in this article. Likewise, design principles tailored to the requirements of a $C^2$ system were used. They are described in the following paragraphs.

5.2.2.1. Intelligent Placement of Cursor

The time spent by the crewmen manipulating the MFD cursor must be minimized if task execution timelines are to be reduced. This is done by automatically placing the cursor where it is needed. For example, if it is standard operating procedure for Task A to be executed after Event X, the system should automatically place the cursor where it is needed to execute Task A following each Event X.

5.2.2.2. Minimize Drag and Click

For desktop computing, it is common to move the screen cursor in a continuous fashion, dragging it along and clicking at the appropriate location. While user-friendly, it is relatively slow, and is difficult to accurately do in a combat system that is moving rapidly over rough terrain. Instead of dragging and clicking, the cursor moves with discrete movements, and is bumped from selection to selection with a bump switch. Using bumping movements is quicker, and improves operations on the move.

5.2.2.3. Automated Data Input

Two major developments in ground-combat systems for the digitized battlefield make possible the automated input of data into $C^2$ reports. First is the addition of sensors, both smart and dumb. Fuel level, ammunition level, system readiness, etc., will all be sensed and digitized. Likewise, the automatic recognition system will provide information on enemy forces that currently only the crewmen can provide. Second, the systems will be electronically integrated. All data and information that is sensed and digitized will be available anywhere within the system. Many report fields that currently are manually filled, will therefore be automatically entered by the system.

## Evaluation

6.1. Existing Army Evaluation Techniques

In past Army ground-combat vehicle development programs, the user interface was evaluated during the development process under static, benign conditions.

Screen designs were presented to users for comment via slide projectors or desktop video display terminals. The user interface was tested for the first time under tactical conditions during Initial Operational Test and Evaluation (IOT&E) exercises.

6.2. New Evaluation Technique

The evaluation technique used in this effort was unique. The user interface was tested, under realistic tactical conditions, before the product ever existed. This was done via man-in-the-loop virtual simulation experiments. This evaluation procedure is described in the following sections.

6.2.1. Test Objective

The objective of the test was to determine the effectiveness of the user interface during simulated tactical operations.

6.2.2. Set Up

The testing consisted of two phases. First, a baseline was established by testing an existing ground-combat vehicle. Then, the user interface described in this article was tested. Each phase consisted of four trials. The test was a company-level exercise. The simulated vehicle was the Platoon Leader for A Company. The mission scenario was a tactical defensive situation. This was broken into six mission vignettes: 1) Tactical planning, 2) Road march, 3) Traveling overwatch, 4) Support by fire, 5) Consolidate and defend 6) Displace to subsequent battle position. This is a realistic order of battlefield events, segmented only to facilitate subjective data collection by asking question to the test subjects immediately following each vignette.

6.2.3. Measurement

Two types of data were collected: 1) Objective and 2) Subjective. Objective data includes: 1) demographic data, and 2) performance data. Demographic data were collected via a standard personal questionnaire. Performance data measures (88 total) were collected digitally and post-test. Subjective data collected included: 1) Work load assessments, and 2) system assessments (human factors questions).

6.2.4. Results

Based on the results of the simulations, the user interface was modified. This was an iterative process, continued until the design optimized for the battlefield environment.

6.2.5. Benefits

The use of virtual man-in-the-loop simulations to evaluate user interfaces for ground-combat vehicles proved extremely effective. User interface deficiencies were quickly identified, and corrected, while the system was still early in its development life cycle. The result will be a dramatic increase in system performance, and a decrease in engineering changes required after production is begun.

## Conclusion

In the development of previous weapon systems, the design of the user interface was given limited priority. Now that we are headed for the Digitized Battlefield, the importance of the user interface has increased dramatically. A process has been installed in the U.S. Army that has improved the user-interface design, and increased the usability and effectiveness of ground-combat vehicles. (Dr. Susanta P. Sarkar is a computer engineer with the U.S. Army Tank Automotive and Armaments Command, AMSTA-TR-R/264 (Sarkar), Warren, MI 48397-5000, DSN 786-5142, 810-574-5142 or e-mail: sarkars@cc.tacom.army.mil)

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# SWOE program validates and accredits physics-accurate environmental data and scene-generation capability with benchmark data base

**by James P. Welsh**

Force XXI and Joint Vision 2010 scenarios consider operations in environmentally different regions of the world. Physics-accurate environmental data and scene-generation capabilities with a benchmark data base, can help predict soldier/system performance as a function of the environmental dynamics that impact missions identified in Department of Defense (DOD) Directive 5100.1.

### Data base assembled

The Smart Weapons Operability Enhancement (SWOE) Joint Test and Evaluation (JT&E) Program has validated and accredited a capability to generate physics-accurate environmental data and scenes, and has assembled a benchmark environmental data base in a Chartered Joint Test for the Office of the Secretary of Defense (OSD), JT&E. This program was directed from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

The validated and accredited physics-accurate data and scene-generation capability with benchmark data base can support DOD Research, Development, Test and Evaluation (RDT&E) Advanced Technology Demonstrations (ATD), and Advanced Warfighting Experiments (AWE).

Activities that provide data and results appropriate to predict performance for the anticipated global range of environmental conditions are limited by time and resources. Results are most often applicable only within the narrow confines of the actual test conditions. Results from any given test or experiment are usually "one of a kind," thus, difficult to extrapolate. Extrapolation can be enhanced by using a validated and accredited physics-accurate data and scene-generation capability with benchmark data base.

### Focusing DOD resources

Application of the validated physics-accurate data and scene-generation capability can help focus DOD resources, including planning and execution of test activities so that results and access to data can be optimized to extrapolate and predict soldier/system performance for the broadest range of environmental conditions. Specifically, the SWOE capability can identify and define the range of test conditions and extrapolate test results using physics. The benchmark data base provides access to environmental data. An added value is for mission rehearsal to predict performance related to the required level of operator training.

The goal is to use physics to maximize the ability to predict the impact of a global range of environmental conditions on soldier/system performance, while minimizing the requirement for collecting massive amounts of "real-world data."

### Background

The global range of missions and declining DOD budgets have obliged political and military leaders to seek options to design, develop, test, plan, rehearse, train, and evaluate new soldier/systems in the context of evolving tactics, doctrine, and environmental intelligence-gathering abilities. One promising option is to exploit validated and accredited physics-accurate environmental data and scene-generation capabilities.

The vision of the SWOE Program is to improve and provide validated and accredited physics-accurate dynamic environmental modeling and simulation with benchmark data base capabilities. During the past 8 years, SWOE has focused the scientific and engineering efforts of more than 200 people from 22 laboratories and eight universities on developing these capabilities for DOD. This vision has been realized through defining, developing, assembling, validating, and accrediting a sophisticated physics-accurate environmental data and scene-generation capability with benchmark data base. Validation has been a key step in realizing the vision.

Validation requires quantitative comparison to samples of "real-world data" (e.g. topography, materials properties, climatology, weather, etc.). Identifying and acquiring the data to initialize, run, validate, and accredit the capability, especially to encompass a wide range of environmental conditions, has made SWOE very sensitive to the purpose, as described in a mission profile, and the spectral, spatial, and temporal scales required for any given operation.

Ultimate applications of the SWOE capability are to support operations to: Compel (Iraq), Deter (Korea), Reassure (Macedonia) and Support (Bosnia). A specific example is related to the U.S. European Command's

experiences in Operation Joint Endeavor. The inability of tactical units to obtain and analyze the appropriate temporal and spatial scale environmental information adversely impacted the ability to forecast the Sava river flood stages, the road conditions specific to mobility, and the ground conditions pertinent to mine and countermine performance. The inability to forecast environmental conditions is directly related to an inability to obtain, analyze, and extrapolate appropriate temporal and spatial scale environmental data in a timely way.

### Example

An example of the SWOE-developed capabilities is provided from a task performed for the Joint Precision Strike Demonstration Program. Available information was used to populate a data base and to provide the input to generate physics-accurate scenes for an area north of the Korean demilitarized zone. Figure 1 is an example of a SWOE physics-accurate environmental infrared (IR) scene generated for Korea.

The IR scene in Figure 1 was generated for an area and time specified for a Korean scenario. Data assembled included: elevation, environmental features (e.g. trees, etc.), and meteorology. The specified area for scene generation was approximately 1-kilometer (km) by 1-km at a spatial resolution of about 2 meters. Geometric models of specified target objects were included with placement, state, and arrangement determined prior to scene generation. Scenes were generated for the IR 8-12 micron waveband. Generated scene times were determined to define the performance envelope for tactical scenarios related to anticipated range of radiance/apparent temperature contrast, distance to target objects, and crossovers in the IR band. Scenes were generated to predict performance for environmental conditions on Oct. 21, 1995 at: 0200 hours, 1300 hours, 1600 hours, and 2000 hours. Input data were from the time period around Oct. 21, 1974.

### Deliverables

1. Documented validation (1,200 pages on one Compact Disc-Read Only Memory (CD-ROM)) through an OSD Chartered Joint Test.
2. A validated and accredited data and scene-generation capability.
3. Benchmark data base on four CD-ROMs including physics-generated data and scenes. The data base on CD-ROM(s) is compatible with National Imagery and Mapping Agency (NIMA) data base products. The CD media is compatible with Windows, Mac and UNIX operating systems and commercial-off-

**SWOE-Generated InfraRed (8-12 micron) Scene for an Area North of the KOREA DMZ Oct. 21, 1995 at 20:00 hours Local.**

**Figure 1. Missile Launchers in SWOE Physics-Accurate Generated Scene Modeled Environmental Conditions: Partly Cloudy, Unrestricted Visibility, Air Temperature, 13.1 °C Model Input: Oct. 21, 1974 at 2000 hours local time, elevation, feature, and meteorology data.**

***The goal is to use physics to maximize the ability to predict the impact of a global range of environmental conditions on soldier/ system performance, while minimizing the requirement for collecting massive amounts of "real-world data."***

the-shelf data base management software, such as the ARC (INFO and GRID) products developed for and used by NIMA.

**Benefits**

SWOE has potential for application to improve modeling and simulation capabilities needed to support test design and data base management, soldier/system performance analysis, field data collection and sampling, mission planning, mission rehearsal, and political and military decision aids and information support systems. Benefits for application of a validated and accredited physics-accurate environmental data and scene-generation capability with benchmark data base include:

1. Better focused soldier/system test planning and execution;
2. Enhanced understanding of soldier/system performance in a greater range of environments;
3. Tool to predict and evaluate the required level of operator training;
4. A physics-accurate environmental mission planning and rehearsal tool; and
5. Level playing field for system evaluation through physics and a Benchmark Data Base. (Dr. James P. Welsh is the Joint Test Director, Smart Weapons Operability Enhancement Joint Test and Evaluation Program, an Office of the Secretary of Defense Chartered Joint Test. He can be contacted at the U.S. Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755-1290, 603-646-4527, telefax 603-646-4730, e-mail: jpwelsh@crrel.usace.army.mil)

## ATMOSPHERIC

# The effect of "X" class solar flares on Army operations, such as GPS

**by John Neander and Fred Gloeckler**

Over the last several decades the sudden eruption of high-energy solar flares has set off a chain reaction of unusual electrical events involving daytime power grid surges, disruption of satellite communication relays, even nuclear power plant shut downs. With today's modern Army becoming more and more dependent on the electrical use of high performance equipment, do the necessary backup procedures exist in order to quickly cover electrical malfunctions? Is the equipment needed to run these procedures in place and properly maintained so that the soldier in the field can still complete the mission as planned? This article discusses the possible range of effects that solar flares could have on electrically dependent field operations; and why this is most significant over the next 5 years.

### What is a solar flare?

A solar flare is defined as an explosion on the sun that usually releases large amounts of energy and particle matter. The sun goes through an 11-year period of solar flare activity. In the current cycle, May 1996 was the minimum for solar flare production. Astronomers keep track of solar flare production by using "sunspot numbers." A sunspot number is defined as an index of solar activity related to the number of sunspots and sunspot groups present on the sun. Sunspots are defined as relatively cool regions in the solar photosphere that appear dark. They contain intense magnetic fields, which provide the energy for solar flares. Sunspots usually occur in groups.

Solar flares are typically classified as either "C", "M", or "X". The X-Ray classification of solar flares is a measure of the strength of a flare. For an "M" class solar flare the X-Ray power output is in the range of 0.01 to 0.1 ergs/square centimeter/second. The "C" class is below a value of 0.01; and the "X" class is above a value of 0.1. "C" class flares rarely cause any problems, but "M" class flares will normally produce a shortwave fadeout in the daylight hemisphere of the Earth. A shortwave fadeout is defined as the end result


Headlines show relevance to society.

**A solar flare is defined as an explosion on the sun that usually releases large amounts of energy and particle matter.**

of a solar flares energy causing an increased absorption of radio waves in the lowest region of the ionosphere, which may make part or all of the high frequency (HF) spectrum unusable. The lower frequencies are effected first and for the longest time intervals. The "X" class flares have enough energy to cause power grid and satellite malfunctions in the daylight hemisphere. If the flare is strong enough, it can reappear in 27 days to cause more harm, since this coincides with the known rotation of the sun.

### Significance of solar cycle from end of 1998 until end of 2002

After a peak sunspot value of 158 was obtained for July 1989, the next peak value is predicted to occur in March 2000 with a value of 165. Note values in the accompanying chart in Figure 1 on Page 14. It should be further noted that sunspot numbers are only an indicator of potential solar flare problems. A sunspot may produce a very strong class "X" flare, several flares of varying intensities, or none at all. Thus, the potential for communications interference and degradation of Global Positioning System (GPS) performance or damage to satellites becomes more probable from August 1998 until December 2002 (not just the peak month of March 2000).

The potential problem areas that need to be addressed now, before they interfere with Department of Defense (DOD) operations, either in a military sense, or a humanitarian operation, revolve around our increasing dependence on satellite communications and other forms of high-speed, land-based electrical data transfers. Based upon past events, as noted in the newspaper headline montage on Page 12, when either an "M" or "X" class flare erupts, some of the areas of possible concern include:

- Radiation degradation and failure of integrated circuits in satellites and high-altitude aircraft;
- Satellite drag increase, orbital errors, shortened lifetimes, early reentry;
- Faults and failures in satellite control systems from unusually high electrical fields;
- Blackouts and fadeouts of long-distance radio communications;
- Interference in ground to satellite

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 11.5 | 11.1 | 10.8 | 10.2 | 9.9 | 10.1 | 10.4 | 9.5 | 10.2 | 10.8 | 11.8 | 14 | 130.3 | |
| 1997 | 16 | 17 | 19 | 22 | 24 | 27 | 31 | 35 | 40 | 45 | 50 | 56 | 382 | |
| 1998 | 45.5 | 51.2 | 57.4 | 63.5 | 68.8 | 75.5 | 83.3 | 91 | 98.4 | 105 | 111.2 | 117.4 | 968.2 | |
| 1999 | 121.9 | 125.4 | 129.9 | 134.3 | 139.4 | 144.6 | 148.4 | 151.6 | 155.7 | 159.2 | 161.3 | 161.9 | 1733.6 | |
| 2000 | 162.4 | 164.7 | 165 | 163.7 | 162.7 | 161.3 | 160.2 | 159.5 | 157.9 | 155.6 | 153.1 | 152.6 | 1918.7 | |
| 2001 | 153.4 | 152.8 | 152 | 152.7 | 152.9 | 151.6 | 150.4 | 149.1 | 146.5 | 144 | 142.4 | 140.3 | 1788.1 | |
| 2002 | 137.3 | 132.8 | 128.3 | 124.6 | 120.9 | 117.8 | 113.7 | 109.3 | 106.3 | 103 | 98.6 | 93.2 | 1385.8 | |
| 2003 | 88.3 | 85.2 | 82.6 | 79.1 | 75.8 | 72.9 | 70.3 | 67 | 62.7 | 59.6 | 58 | 57 | 858.5 | |
| 2004 | 56.4 | 55.2 | 53.6 | 51.6 | 48.8 | 45.2 | 41.4 | 39 | 38.3 | 37.1 | 34.8 | 32.3 | 533.7 | |
| 2005 | 29.8 | 27.6 | 25.8 | 24.6 | 23.9 | 23.2 | 22.6 | 21.7 | 20.4 | 19.4 | 18.8 | 18.2 | 276 | |
| 2006 | 17.4 | 16.6 | 15.6 | 14.4 | 13.3 | 12.5 | 12 | 11.4 | 10.7 | 10.1 | 10 | 10.2 | 154.2 | |
| | | | | | | | | | | | | | | |
| | 792.7 | 795.4 | 798.6 | 801.7 | 803.2 | 806 | 809.1 | 811 | 816 | 819.3 | 821.2 | 824.7 | | |
| | | | | | | | | | | | | | | |

**Figure 1. This graph is courtesy of IPS Radio and Space Services.**

# PREDICTED SOLAR FLARE FREQUENCY OVER THE NEXT DECADE

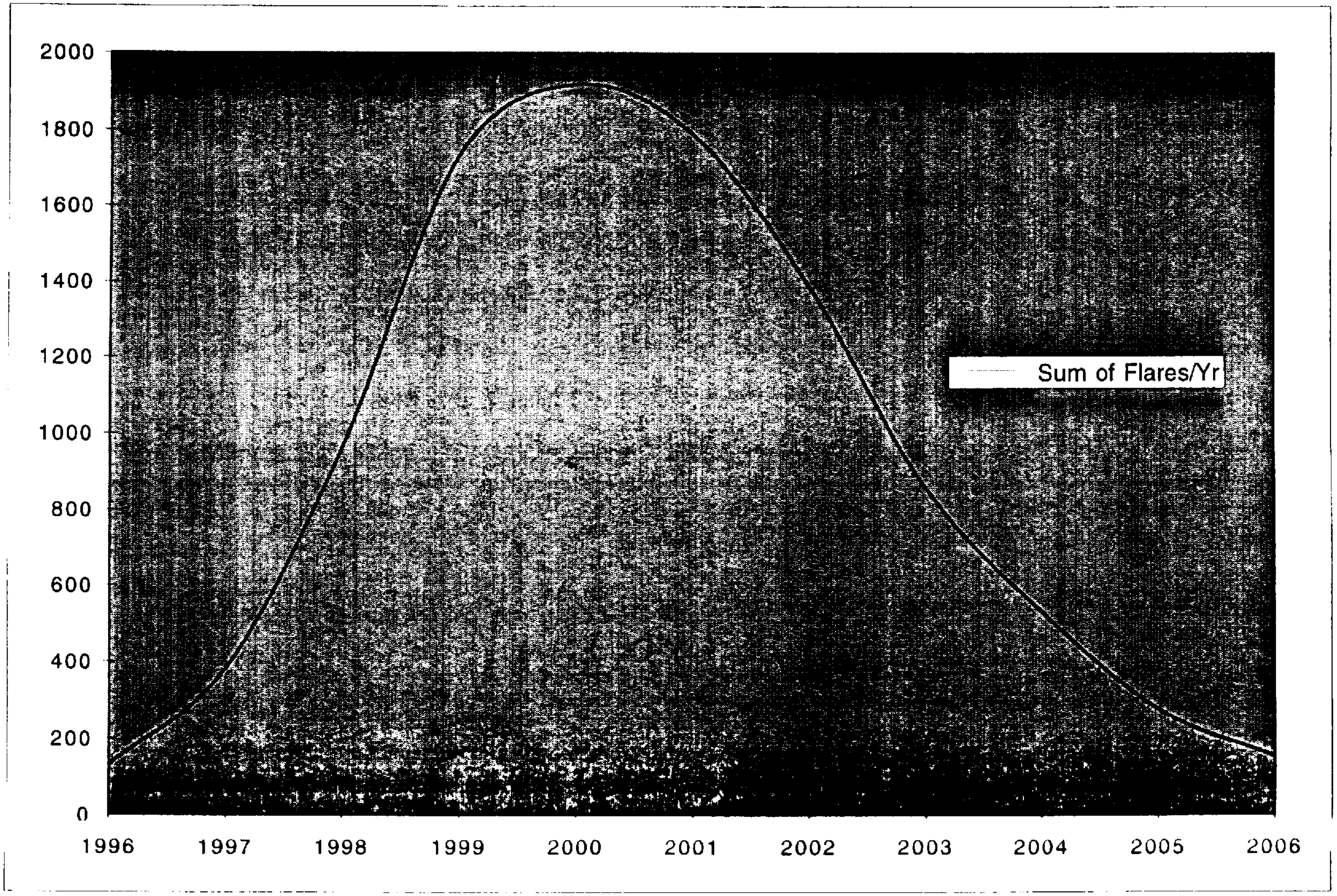


Figure 2. This graph is courtesy of IPS Radio and Space Services.

communications;

- Position errors in externally referenced navigation systems;
- Induced voltage interference on long line telephone links; and
- Power distribution system outages - blackouts and brownouts.

These problems will then lead to the following:

- Loss of accuracy in GPS;
- Degradation of Geophysical Surveys;
- Blinding of over the horizon and other types of radar; and
- Disruption of communications.

A case study is the March 1989 power failure in Quebec, Canada. On March 13, 1989, a large solar-induced magnetic storm played havoc with the ionosphere, and the Earth's magnetic field. This storm, the second largest storm experienced in the past 50 years, totally shut down Hydro-Quebec, the power grid servicing Canada's Quebec province. "At 2:45 a.m., the storm, which resulted from a solar flare, tripped five lines from James Bay and caused a generation loss of 9,450 megawatts (MW). With a load of some 21,350 MW at that moment, the system was unable to withstand this sudden loss and collapsed within seconds. The system-wide blackout resulted in a loss of some 19,400 MW in Quebec and 1,325 MW of electrical exports. Service restoration took more than 9 hours. By noon, the entire generating and transmission system was back in service, although 17 percent of Quebec customers were still without electricity." At the same time that this power grid was failing, this solar flare destroyed a Japanese TV relay satellite with the replacement cost put at $300 million.

It should be noted that the sunspot number for March 1989 was more than 149 and didn't drop below 149 until May 1990; the strongest solar flare for that time interval was on March 13, 1989. In any given solar

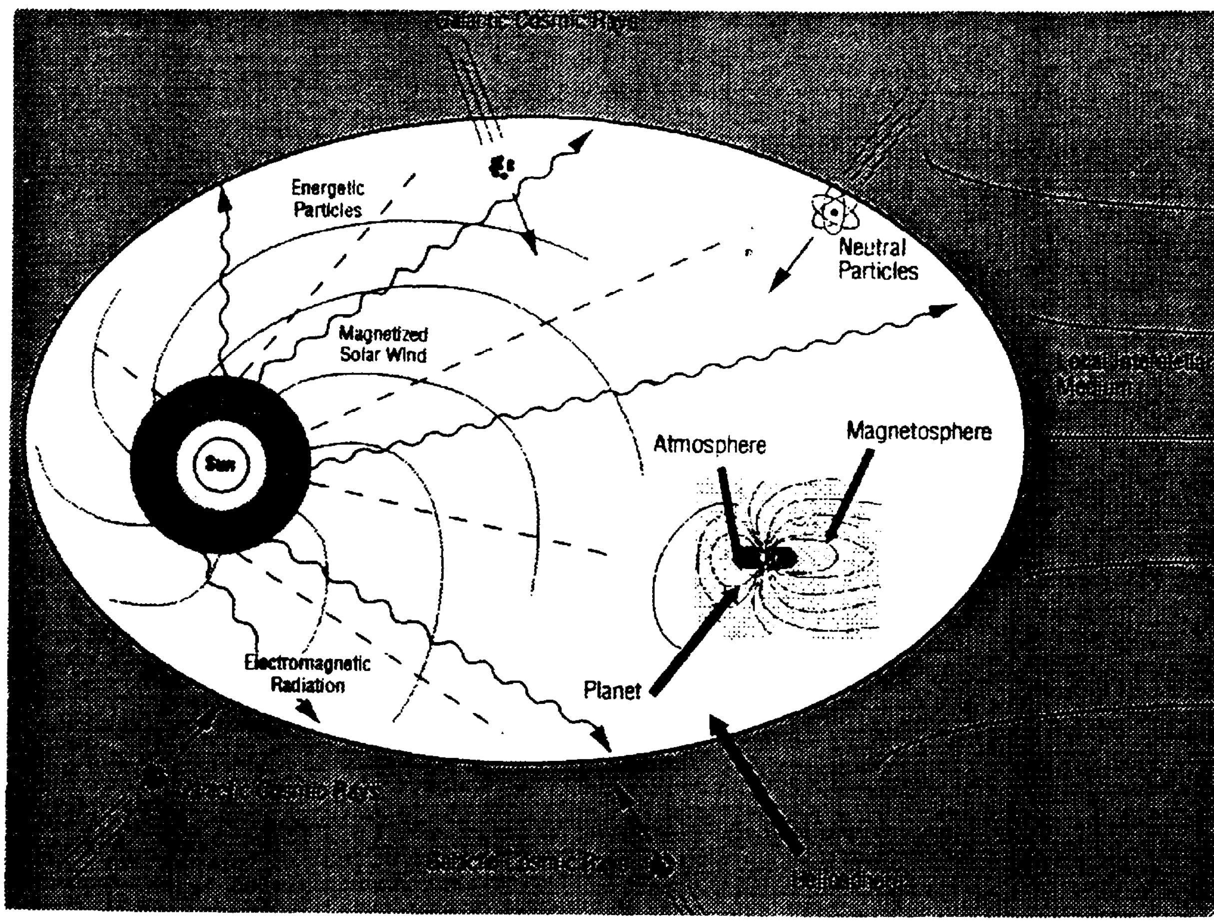


**Figure 3. This graphic depicts the influence of energetic solar radiation and the solar wind on the magnetosphere and upper atmosphere of the Earth.**

cycle the data on the 20 worst solar flare/geomagnetic storms shows that most (16 out of 20) occurred after the time of solar maximum in a particular cycle; and that the equinox months (March-April and September-October) were the worst months with 13 entries out of 20. In Salem, N.J., this March 13, 1989 storm knocked out a nuclear power plant for 6 weeks, with an operating loss of $20 million.

Another solar flare in March 1991 caused a Canadian Research in Earth and Space Science (CRESS) satellite to lose one-fourth of its function during the resultant magnetic disturbance. This lose was estimated at $80 million.

A solar flare that erupted on Jan. 20, 1994, caused severe damage to two Canadian transmission relay satellites (ANIK E-1 and ANIK E-2). ANIK E-2 had a lifetime of 10 years reduced to 1-year. The resultant replacement was made at an additional cost of $400 million.

### What is a GPS?

GPS is a satellite-based radio-navigation system developed and operated by the Department of Defense (DOD). GPS permits land, sea, and airborne users to determine time and three-dimensional position and velocity 24 hours a day, in all weather, anywhere in the world. GPS is dual-use technology. The basic positioning capability is available to everyone. However, enhanced accuracy and some other features are available only to the military and other "authorized" users. GPS has a wide variety of applications in the civil and military communities.

GPS has three segments: space, control and user. The "Space Segment" has 24 operational satellites in six circular orbits 20,000 kilometers (km) or 10,900 nautical miles (nm) above the Earth at an inclination angle of 55 degrees with a 12-hour period. The satellites are spaced in orbit so that at any time a minimum of six satellites will be in view to users anywhere in the world. Each GPS satellite continuously broadcasts accurate position and time signals on two carrier frequencies, which are designated L1 and L2.

The "Control Segment" consists of a master control station (MCS) in Colorado Springs, Colo., with five monitor stations and three ground antennas located worldwide. The monitor stations collect ranging information from all GPS satellites in view and send it to the MCS. The MCS computes precise satellite clock corrections and orbits, which are formatted into updated navigation messages for each satellite. The updated information is transmitted to each satellite via the ground antennas, which also transmit and receive satellite control and monitoring signals.

The "User Segment" includes the receivers, processors, and antennas that allow land, sea, or airborne operators to receive the GPS satellite broadcasts and compute their precise position, velocity and time. The user's receiver measures the time delay for a satellite signal to reach the receiver, which is a measure of the apparent range to the satellite. Measurements collected simultaneously from four or more satellites are processed to solve for time and three-dimensional position and velocity.

### Different ways to use GPS

Because of the (relatively) low-cost and ease of use of GPS receivers, they have become pervasive in many applications requiring precise position and/or time. Depending on the end requirements, a receiver may stand alone or be embedded as a component in a host system. A list of applications would include: general navigation; weapon and target acquisition system emplacement; cargo tracking; resupply; recovery of vehicles and personnel; position location for situation awareness and command and control; boundary excursion monitoring; survey; construction; munitions guidance; attitude determination; and time synchronization for communication links, unit operations, and power grids.

To improve relative accuracy, GPS is frequently augmented by information acquired at a reference station. In real-time Differential GPS (DGPS) corrections determined at the reference station are broadcast for application by the remote user. Depending on the required accuracy, GPS receivers may receive only the L1 signal or both the L1 and L2 signals.

### Space weather effects on GPS

The sun-earth environment is the region of space extending from the surface of the sun out to, and including, the Earth's ionosphere and magnetic field. Changes to conditions in the sun-earth environment are often called "space weather" and this can cause significant damage to technological systems, particularly to communications. Space weather results from changes in the speed or density of the solar wind, which is the continuous flow of charged particles from the sun past the Earth and into interplanetary space. This flow distorts the Earth's magnetic field, compressing in the direction of the sun and stretching it out in the anti-sun

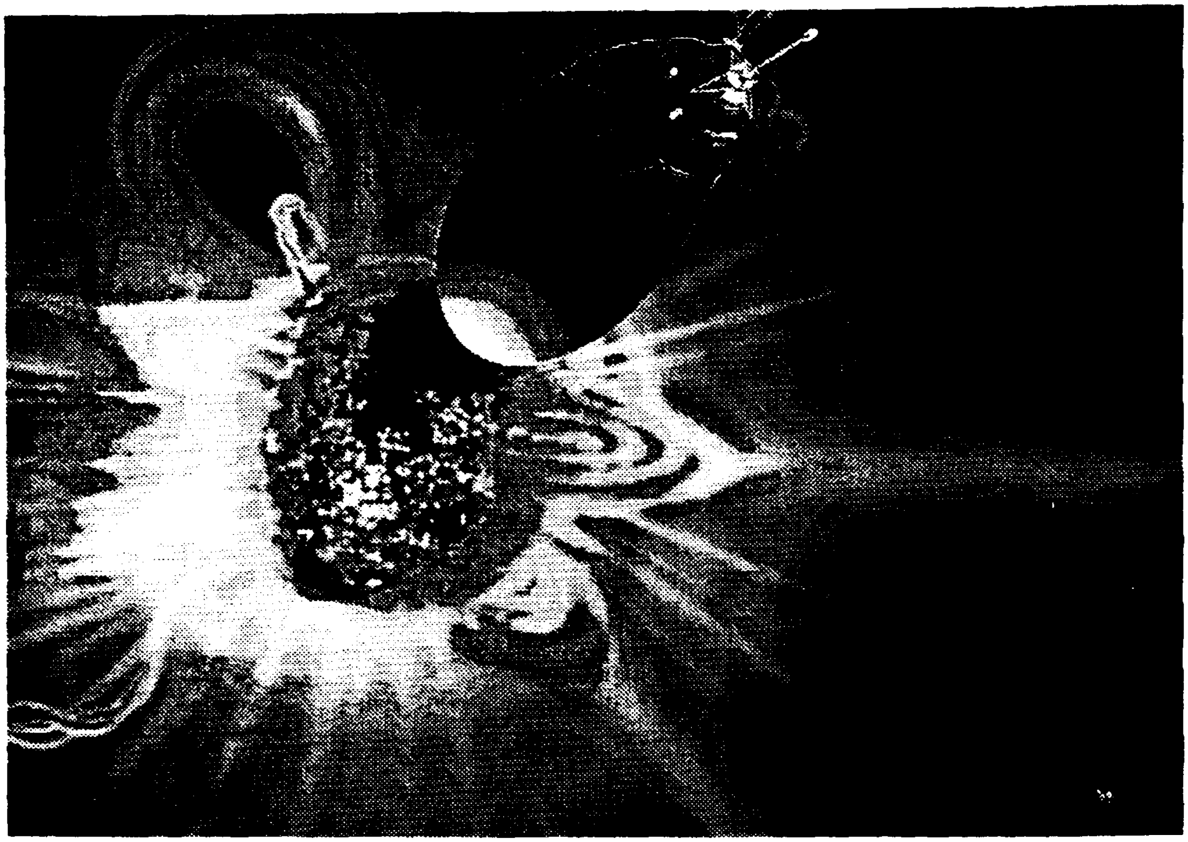

**Figure 4. This graphic depicts "X" class solar activity and satellite analysis.**

direction. Fluctuations in the flow of solar wind cause variations in the strength and direction of the magnetic field measured near the surface of the Earth. Abrupt changes in this dynamic medium are called geomagnetic disturbances. One of the methods that the sun can use to produce a geomagnetic disturbance or ionospheric storm is a solar flare that intercepts the Earth's orbital path around the sun.

As previously discussed, satellites and their control networks can be effected by space weather in various ways. Since GPS satellites travel through the Van Allen radiation belts and carry nuclear detonation (NUDET) sensors, they are designed to withstand severe radiation environments, such as those caused by solar flares. GPS satellites survived the previous solar maximum and typically exceed their designed on-orbit lifetime. Operational control and housekeeping focus on minimizing reduction of GPS services.

User receivers are mainly affected by ionospheric disturbances induced by solar storms. The affects include disruption of GPS signal reception, reduced accuracy and disruption of augmentation signals, such as Differential GPS (DGPS) corrections. The time of satellite observation and receiver location also influence the degradation magnitude.

The ionosphere is the layer of the Earth's upper atmosphere that is partially ionized by solar x-rays and ultraviolet radiation and energetic particles from space. It ranges in altitude from about 50 km to more than 1,000 km. The ionosphere induces delays in the modulated GPS signals, which are proportional to the electron density along the signal path and inversely proportional to the square of the carrier frequency. Though it may seem strange, the phase of the carrier wave is advanced an equal amount. The electron density is influenced by the solar energy impinging on the ionosphere. The charged particles tend to recombine at night, reducing the ionospheric delay. Depending on conditions, the ionospheric delay on GPS signals may result in range errors of less than a meter, to more than 100 meters. At a given time and location, the ionospheric delays on signals from different GPS satellites will be different.

Those GPS receivers which receive both the L1 and

L2 frequencies can make use of the ionospheric delay frequency dependence to accurately compensate their range and range rate measurements. Some military and "high end" civil receivers have this capability.

Many receivers, like the AN/PSN-11 Satellite Signals Navigation Sets, commonly known as a Precision Lightweight GPS Receiver (PLGR) receive only the L1 signals. The following techniques are used to compensate single frequency measurements for ionospheric delay:

a. The GPS satellites broadcast parameters of an ionospheric model, which reduces ionospheric-related errors approximately 60 percent Root Mean Square. Since the model parameters are derived from historic data and are updated infrequently, the model doesn't compensate for solar storm-induced errors very well.

b. A DGPS reference receiver determines signal corrections at a known location. These corrections are applied to cancel errors at a remote receiver, under the assumption that systematic errors, including ionospheric delay, are nearly the same at both sites. Ionospheric delay tends to decorrelate with distance between the reference and remote receivers. Depending on the type of DGPS system, position errors will increase or the inter-receiver distance must be decreased during times of large ionospheric delays. Depending on update rate, DGPS systems can track fairly rapid changes in ionospheric delay.

c. Some systems, like the future Federal Aviation Administration Wide Area Augmentation System (WAAS), use a network of reference receivers to measure ionospheric delay over large areas. The measurements are used to determine the coefficients of an ionospheric model, which are broadcast to the user over a separate communications link. This model is much more dynamic and accurate than the one broadcast by the GPS satellites. It provides greater spatial fidelity over long distances than standard DGPS but doesn't react as quickly to temporal changes.

In solving for position and time, that portion of ionospheric delay, which is common to all satellites will be reflected as a receiver clock error. Position errors result from differences in ionospheric delays between satellites. Ionospheric delay varies diurnally, peaking at about 1400 local time and decaying to a minimum before dawn. Typically, ionospheric delay is greatest in the equatorial belt, approximately "30° either side of the Earth's magnetic equator, with highest levels around ±15° to ±20°." This belt covers about 50 percent of the Earth's surface.

Ionosphere irregularities can cause scintillation, which may result in short-term signal fading and rapid carrier-phase changes. These effects may cause GPS receivers to lose lock. L2 loss of lock is much more likely on receivers which employ "codeless" L2 tracking techniques rather than true P/Y code tracking. Scintillation occurs most often in the equatorial region. Equatorial scintillation fading can last for several hours interspersed with intervals of no fading. The times of strong equatorial scintillation fading are limited to approximately an hour after sunset to local midnight, though they sometimes extend to dawn. Equatorial scintillation is seasonal. There is little chance of significant scintillation in the American, African, and Indian longitude regions from April through August. Scintillation effects are maximized during these months in the Pacific region. The situation is reversed September through March. Scintillation effects also tend to follow the solar cycle. Magnetic storm activity can produce scintillation effects in the auroral and polar regions. These areas cover only about 7 percent of the Earth's surface. The affected area may extend well into the mid-latitudes during very severe magnetic storms. While auroral region scintillation effects aren't as strong as those in the equatorial region, they may last for hours or even days and aren't limited to the late evening hours. Space weather also may induce outages or data loss in links used to communicate DGPS and GPS survey data.

**Mitigating space weather effects on GPS user**

For precise survey applications, baseline lengths may have to be reduced and observation times increased to counter the effects of increased ionospheric delays and cycle slips on ambiguity resolution. Military surveyors should be equipped with the Navigation Set, Satellite Signals; AN/GSN-13, commonly known as the GPS Survey System (GPS-S), rather than commercial survey receivers. The GPS-S tracks all satellites in view on both L1 and L2. When keyed, the GPS-S tracks the L2 code, which minimizes loss of L2 data and greatly enhances ambiguity resolution compared to L1 only receivers.

Where possible, surveyors should plan their operations for the seasons and times of day when ionospheric effects are minimized. On-site data recording and post-processing should be considered as a backup to real-time DGPS or survey data communication links. Near-term space weather forecasts may be helpful in planning daily operations. One source of current forecasts is the National Oceanographic Atmospheric Administration (NOAA) Space Environment Center at: http://www.sel.noaa.gov/today.html. Another source is the IPS Radio and Space Service at: http:/www.ips.gov.au/asfc/usa_hf/.

It's probably not practical to plan general navigation and other operations around space weather effects. Soldiers should be trained to expect reduced GPS availability and degraded accuracy in the regions and times of increased ionospheric effects. Training should reinforce general navigation skills and use of backup positioning and navigation systems. Receivers which can simultaneously receive L1 and L2 signals from all satellites in view will improve the situation. However, PLGR probably still will be the predominant military GPS receiver during the peak of the next solar cycle.

### Contingency planning

Within 4 years, the current solar cycle will reach its solar maximum. During the time of solar maximum, flares 10 times bigger than any recent event will occur four to five times a day. Once every 24 to 48 hours, a flare will occur that is 100 times bigger. These are the flares that are most often classified as being in the "X" class with the highest probability of causing damage to electrical components circling the atmosphere, contained in our atmosphere, or situated on land or ocean-based structures.

Contingency plans need to be formulated now, while discussion of backup plans and emergency "work arounds" are still possible. If contingency plans are in place, now is the time to run checks on them to make sure the plans are current. Possible areas of involvement would be:

- Minimize orbital corrections until after a flare has subsided;
- Isolate power distribution grids from each other;
- Desensitize or disable automatic control systems on power grids;
- Select alternate frequencies for long-range communications;
- Keep backup positioning systems in place for emergency "as needed" use;
- Highlight military electrical power needs in conjunction with tie-ins to civilian power grids; and
- If the power grid fails, how will these military demands for power be met?

### Conclusion

The Army, at any time may be asked to respond to a military "threat," or to be a part of a "police" action, or to aid in some form of humanitarian "relief" action. Can we risk any significant disruption of our GPS capabilities during these times of "high visibility?" Certainly not! If an "X" class solar flare has even a slight possibility to disrupt our GPS system in the air; and a far greater possibility of disrupting less sophisticated field systems on the ground, then a reliable backup procedure, that is routinely updated, has to be in place. The key then is to make certain that those backup procedures are fully tested. For example, having an operational "backup" generator in place, won't help to complete the assigned mission, if its fuel tanks remain empty.

Space weather can adversely affect operations just like terrestrial weather. The potential threat from daylight exposure to "X" class solar flares will only become a reality if the proper planning and preparation is allowed to fall by the wayside. The soldier needs to be prepared in order to minimize the impacts of disruptions and still complete the mission as planned. (John Neander is a research meteorologist at the U.S. Army Topographic Engineering Center, CETEC-TR-R, 7701 Telegraph Road, Alexandria, VA 22315-3864, DSN 328-6651, 703-428-6651 or e-mail: jneander@svl.tec.army.mil. Fred Gloeckler is an electronic engineer at the U.S. Army Topographic Engineering Center, CETEC-TD-T, 7701 Telegraph Road, Alexandria, VA 22315-3864, DSN 328-6777, 703-428-6777 or e-mail: fgloeck@tec.army.mil)

# TEST AND EVALUATION

## *Integrated Meteorological System completes Follow On Test and Evaluation*

**by Jeffrey S. Swanson**

In March 1997, the Integrated Meteorological System (IMETS) completed Follow On Test and Evaluation (FOT&E). Testing provided data used to perform an independent operational assessment of the operational effectiveness and suitability of the Block II system. The test results supported a favorable Milestone III decision (April 1997) to begin fielding the Block II IMETS.

IMETS is the meteorological component of the Intelligence and Electronic Warfare (IEW) subelement of the Army Battle Command System (ABCS). IMETS provides commanders at all echelons with an automated weather system to receive, process, and disseminate observed weather conditions, weather forecasts, and environmental effects decision aid to all Battlefield Operating Systems (BOS). The system resides in a Standard Integrated Command Post Shelter (SICPS) mounted on a High-Mobility Multipurpose Wheeled Vehicle (HMMWV), heavy variant. IMETS receives weather information from civilian and defense meteorological satellites, Air Force Global Weather Center (AFGWC), artillery meteorological teams, remote sensors and civilian forecast centers.

### Satisfying Warfighter's needs

IMETS processes and collates weather observations, forecasts, and climatological data to produce timely and accurate weather products tailored to the specific Warfighter's needs. The other BOS in ABCS depend on IMETS to provide the following:

- satellite images for Intelligence Preparation of the Battlefield and terrain analysis;
- near-real-time data for safe aviation operations;
- landing and drop zone data for Airborne operations;
- current satellite observations to enhance accuracy of deep fire support systems;
- current and forecasted weather for Combat Service Support planning;
- winds and humidity for Nuclear, Chemical and Biological (NBC) planning; and
- communications linkage from the Department of Defense and commercial weather satellites and commercial forecast centers to contingency forces.

In July 1994, the Block I IMETS completed Initial Operational Test and Evaluation (IOT&E). This was followed by a favorable MS III full-rate production and fielding decision in December 1994. Fifteen Block I IMETS were fielded to high-priority units during FY94/95.

The Block II IMETS features an upgrade to the Sun Sparc 20 High Capacity Computer Unit (HCU), integration of the Air Force Tactical Forecast System (TFS), new weather application software, software enhancements, and the implementation of the Defense Information Infrastructure Common Operating Environment (DII COE) architecture. The Battlescale Forecast Model (BFM) and the Integrated Weather Effects Decision Aids (IWEDA) are the new additions in the category of new weather application software. The BFM is the focal point for tactical weather forecasts. The BFM enables forecast of weather effects and visibility down to a 10 kilometer square area. IWEDA uses the BFM output to generate weather effects on tactical systems. Weather, the force multiplier, can then be used by decision makers for tactics.

The test unit for the FOT&E consisted of Air Force Specialty (AFSC) JIW071A airmen operators and Military Occupational Specialty (MOS) 31U20 maintainers. The airman came from the 18th Weather Squadron, Air Force Global Weather Center (AFGWC), and the 21st and 19th Air Support Operations Squadron (ASOS) and Headquarters, Forces Command. Maintenance personnel come from the 264th and 189th Combat Support Battalion (CSB). The FOT&E was planned and conducted as an Integrated Test and Evaluation (IT&E) effort under the control of a U.S. Army Operational Test and Evaluation Command (OPTEC) System Team (OST). The OST members represented U.S. Army Test and Evaluation Command, Test and Experimentation Command, Evaluation Analysis Center, with the Operational Evaluation Command serving as chair.

### Testing activities

The FOT&E consisted of pretest activities (operator, data collector, and test team training and an end-to-end demonstration), pilot test, record test, and post test activities. Three IMETS participated in the test and functioned as corps, division, and separate brigade assets. The 10-day test took place at Fort Lewis, Wash. There were two 120-hour missions (24-hour days) in accordance with the Operational Mode Summary/Mission Profile (OMS/MP) in a field environment.

Objective and subjective data were collected during all phases of the test. The record test was conducted using a Master Events List (MEL) based on the OMS/MP an Army Tactical Command and Control System (ATCCS) scenario. The MEL was designed to exercise all automated data processing, messaging, communications and interoperability of the IMETS. The IMETS was required to road march a minimum of 12 times, completing set up (40 minutes) and tear down (20 minutes) within the required time. Each system demonstrated the capability to acquire meteorological data from AFGWC, geostationary and polar orbiting satellites, and other IMETS. Operators were required to receive instructions, orders, and other requests for information from ABCSs and generated a wide variety of meteorological products for dissemination back to the ABCS user via Army Mobile Subscriber Equipment and over Single Channel Ground and Airborne Radio System (SICGARS) using U.S. Message Test Format (USMTF) and via client-server (home page) architecture. The operators also were required to perform a full range of duties while at Mission-Oriented Protective Posture Level 4 (MOPP4).

**Capabilities demonstrated**

IMETS met or exceeded all Critical Technical Parameters and Operational Test Measures of Performance. The system demonstrated the capability to provide automated weather data, weather effects data, and weather forecast products to tactical commanders for near-real-time use in an operational environment. The design and resourcing of the IMETS allow it to meet all critical tasks within standard, meet the reliability and availability parameters, meet all technical design parameters, and be assessed suitable by the crew and Air Force and Army user community. The system was deemed effective and suitable for its mission. IMETS received a favorable MS III decision in April 1997 and was field to the 82nd Airborne Division, 18th Airborne Corps, and the 18th Airborne Corps Aviation Brigade at Fort Bragg, N.C., in July 1997.

IMETS is a product of, and managed by, the Army's Intelligence Fusion Project Management Office under the direction of the Army Program Executive Office for Command, Control and Communications Systems (PEO $C^3S$).

For more information, contact the IMETS Project Office, Project Director, IMETS, Marvin H. Dubbin, ATTN: SFAE-C3S-MET, White Sands Missile Range, NM 88002, DSN 258-1984, 505-678-1984 or telefax 505-678-0343. (Jeffrey S. Swanson is a meteorological technician with the U.S. Army Research Laboratory, Information Science and Technology Directorate, Battlefield Environment Division, AMSRL-IS-EW, White Sands Missile Range, NM 88002, DSN 258-1801, 505-678-1801, telefax 505-678-0343 or e-mail: jswanson@arl.mil)

## CRREL provides support to Operation Joint Endeavor

**by Maj. Bruce L. Gwilliam**

Snow and cold are significant inhibitors to the operations of U.S. Forces. Engineers, in particular, are sensitive to the impacts of the snow and ice. Operation Joint Endeavor was no exception. The 502d Engineer Co. experienced such problems as they were tasked with emplacing a ribbon bridge to cross the Sava River in the town of Zupanja, Bosnia. Problems due to flooding occurred as a result of warm weather, melting snow and torrential rain in late December 1995.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, N.H., along with the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Miss., were called in to provide support. The initial effort was to understand the hydrology; WES was responsible for the flow forecast and CRREL for providing estimates of snow and snowmelt.

#### Problem definition

Knowledge of the drainage basin and river were essential. The basin was defined as having complex terrain, with more than 60,000 square kilometers of area ranging in elevation from a few hundred meters to more than 2,000 meters. Historical river flow from both existing and destroyed gages provided the key to understanding the river. Specific efforts were made to collect the stage elevation data from the few working gages.

Using stage data from Slavonski-Brod, the nearest operational gage, it was possible to observe the start of a flood and estimate its arrival at the crossing site. Thus, it was possible to provide limited near-term warnings. However, the Bosna River basin lies between Slavonski-Brod and Zupanja, an area that comprises more than 20 percent of the Sava watershed.

#### Data acquisition

Lack of direct observation of river flow was further complicated by limited weather observations. The Sava watershed, during the winter months, experiences frontal precipitation and moderate temperatures, which fluctuate around the melt/freeze point. Both the Sava and Bosna watersheds can experience snow one day and melt the next.

Knowledge of the weather including precipitation, temperature and snow are critical to estimating how much water will flow into the river. Of the 20 weather stations reporting, the majority of them lie in the plains. Three sites provide observations in the intermediate elevations and one in the upper elevations. Only five of these sites provide observations within the Bosna watershed.

#### Modeling and imagery

Knowing when and where snow lies becomes critical. These patterns provide the base for understanding the spatial behavior of the weather, snow and melt contribution to the rivers. This can be accomplished by estimating the snow cover using the limited weather reports extrapolated over the whole basin and/or remote sensing.

A modeling system was developed to use these data, along with weather reports, to forecast changes in the snow cover. The basins were divided into specific model classes based on meteorologic regions and topographic elements, such as elevation, slope, and aspect for modeling. These forecasts are the basis for river flow predictions as snow melts.

On cloud-free days it is possible to estimate a snow cover fraction using Advanced Very High-Resolution Radar (AVHRR) from the National Oceanographic and Atmospheric Association. Coupling the limited weather observations with infrequent satellite imagery, it is possible to estimate spatial patterns for both snow cover and melt with the areas of concern, and update forecast models.

#### Hydrologic forecasting

To maintain accuracy, flow forecasts must extend into the future. Thus, weather forecasts for the next 5 days were required and provided by Air Force weather personnel for nine key locations. These limited forecasts were then extended spatially throughout the basins. Using Snow Therm, a CRREL-developed snow model for each of the defined areas, it was possible to estimate both snow cover and melt for the next 5 days.

These forecasts of snow and melt are convertible into flow contributions per basin. The forecasts provided the ability to estimate the condition of the river at the crossing site and to schedule operations. Operations could be accelerated or slowed down to avoid expected floods or low flows. Flow forecasts were run every day to include the current weather since the forecasted and observed weather often varied.

### Technical support

A second aspect of support is response to queries from the field. Specific issues included base camp support, movement and equipment. Among the many inquiries received were: base support concerning snow loads and structures; concrete admixtures to allow pouring of concrete at temperatures below freezing; and methods to reduce the problems of mud. Others included tracked vehicles on icy and snow packed roads, use of portable toilets, use of tire chains, prevention of water from freezing, significance of various tire pressures for winter driving, and reduction of ice accumulation on metal bridges.

Snow-clearing support included both acquisition of plows for Small Emplace Excavator and High-Mobility Multipurpose Wheeled Vehicles, and training on their use. Sand and salt spreaders, and appropriate snow and ice melters were defined for maintaining roads. Impacts of snow cover on mines and clearing procedures were provided. Critical to this process was problem identification by the field unit, appropriate task forwarding by higher headquarters, and communication and coordination between CRREL, the chain of command, and the field unit.

### Summary

CRREL, WES and the other Engineer laboratories exist to provide technical solutions to the problems of the soldier in the field. Support to Bosnia was no exception. Working in cooperation with the V Corps Deputy Chief of Staff, Engineer, an effective and efficient procedure for pass through of requirements was established. Technical questions about the impact of cold and snow on personnel, equipment and operations were provided. Provision of snow cover and melt estimates, a key element of river flow forecasting, provided the units the lead time to assure safe and timely crossing of the Sava River.

For more information on this article, contact Maj. Patrick M. Marr, chief of the Plans and Programs Office, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH 03755-1290, 603-646-4386.) (At the time this article was written, Maj. Bruce L. Gwilliam was the deputy chief of staff at CRREL.)

## IMETS weather digitization provides significant support to Force XXI

**by Eugene S. Barnes**

Weather — the battlefield factor that has influenced the outcome of wars throughout mankind's history from the days of the ancient charioteers to the present day of "smart/brilliant" weapons. Historically, the battlefield leader who could best cope and use the adverse conditions to an advantage either defensive or offensive would carry the day. Using today's leading edge communications and weather modeling, processing and display technologies, the effects of weather are being forecast and displayed on modern digital command and control equipment as a part of Force XXI, the Army's premier Advanced Warfighting Experiment (AWE).

### Revolutionary concept

The heart of the new capability is the Integrated Meteorological System (IMETS), which is augmented with the latest in meteorological satellite imaging and processing equipment. As recently demonstrated during Brigade Task Force XXI at the National Training Center (NTC), Fort Irwin, Calif., and currently participating in Division XXI, Fort Hood, Texas, the IMETS represents a revolutionary concept in digital weather support. By combining the Army Battle Command System (ABCS) Common Operating Environment (COE) interoperability with the capability to ingest, compute and forecast weather impacts on the battlescale of interest to the warfighter, the IMETS places the vital weather information at the fingertips of the battle decision makers.

The Force XXI IMETS prototype is operated by Air Force weather personnel from the 3d Weather Squadron, the Air Force Combat Weather Center (AFCWC) and the Air National Guard's 209th Weather Flight. IMETS culminated the combined research and development efforts of the U.S. Army Research Laboratory (ARL), Army Space Command (ARSPACE), and Project Director-IMETS (PD-IMETS).

When deployed to the field, the IMETS is part of the Tactical Operations Center (TOC) of the echelon supported, such as Corps or Division. The IMETS digitally interfaces with other ABCS elements of the TOC through the Local Area Network (LAN). Mounted on a Heavy High-Mobility Multipurpose Wheeled Vehicle (HMMWV) with a Standardized Integrated Command Post System (SICPS), the IMETS is a self-contained tactical weather production center capable of ingesting near-real-time, high-resolution meteorological satellite imagery and raw weather data from the Department of Defense (DOD) weather sources, such as Air Force Global Weather Center (AFGWC).

***The program's success can be attributed to the partnership forged between the Army R&D community, private industry and skilled Air Force weather operator personnel.***

Complementing the IMETS and representing the contribution of space-based assets to improved meteorological surveillance of the battlefield, the ARSPACE Deployable Weather Satellite Workstation (DWSW) acquires and processes real-time, high-resolution (as low as 0.55 kilometer (km) per pixel) imagery and vertical sounder data (wind, temperature and moisture fields at altitudes from surface to 50,000 feet) from both polar orbiting and geostationary weather satellites. Local/regional weather data and gridded global scale weather model output fields from all sources are processed by two onboard work stations, the Tactical Forecast System (TFS) for large-scale weather patterns and the Weather Effects Workstation (WEW) for modeling small-scale weather phenomena and producing tactical decision aids over the Army warfighter's Area of Operations (AO).

### Producing decision aids

Air Force Weather Team (WETM) operators use the WEW to ingest AFGWC data bases to initialize mesoscale tools. In addition to automatically displaying, contouring and streamlining data fields on terrain map backgrounds over the area of interest, the WEW produces Army electro-optical decision aids and downwind messages. The most powerful tools on the WEW are the Atmospheric Sounding Program (ASP) and the Battlescale Forecast Model (BFM). The BFM forecasts temperature, humidity and winds over complex terrain at 10 km resolutions and vertically to 18,000 feet for up to 24 hours. Using current data and BFM output, the ASP predicts atmospheric moisture, icing, turbulence and convection anywhere over the area of interest. The BFM and ASP, together with other forecaster input, drive the new UNIX-based version of the Integrated Weather Effects Decision Aid (IWEDA). Using the client-server architecture of ABCS, Army operators of the Maneuver Control System (MCS), All-Source Analysis System (ASAS) and other Battlefield Functional Area (BFA) work stations within the TOC, can select weapon system and mission configurations using IWEDA, and generate tailored weather impact map overlays to match battlefield activities.

### Tailoring weather products

The IMETS uses Homepage technology to "push" tailored weather products to customers at all echelons. The Staff Weather Officer tailors weather products for each element of the force package (e.g. artillery, infantry, air defense, etc.). Warfighters within reach of the TOC LAN can then access weather products of interest to their portion of the decision process off the weather Homepage. Using the Global Broadcast Service Battlefield Awareness Data Dissemination (GBS-BADD) broadband communications system, weather products are forwarded to other command and control elements at "Brigade and Below" where the Warfighter Associate (WFA) work station display the weather homepage. In addition, text messages, such as weather warnings and chemical downwind reports can be transmitted in U.S. Message Text Format (USMTF) using the Common Message Processor.

Without a doubt, the success of Force XXI weather operations directly reflects the skills and dedication of the Air Force operators that make the system work. Concepts and techniques evaluated in the Force XXI AWEs will have far-reaching impacts on how WETM teams are structured and how weather intelligence is integrated into the warfighter's decision making process. Many of the technologies demonstrated in Force XXI was fielded in 1997 in the Block II IMETS

The program's success can be attributed to the partnership forged between the Army research and development community, private industry and skilled Air Force weather operator personnel. With this partnership, future historians may well mark the 21st century as the era when the outcome of the battle was determined in advance by the warfighter's ability to know and exploit the impact of the forces of nature.

(Eugene S. Barnes is a meteorologist with the U.S. Army Research Laboratory, Information Science and Technology Directorate, Battlefield Environment Division. He is stationed at the Air Force Combat Weather Center, Hurlburt Field, Fla., where he is serving as the Joint Development Coordinator. He can be contacted at DSN 641-5349 or e-mail: barnese@hurlburt.af.mil.)

## TEC investigates temperature frequency estimation

**by Dr. Paul F. Krause**

Although prior research on the subject of surface air temperature is quite abundant in the professional literature, little attention has been paid to examining the frequency of occurrence of this parameter. A number of professional fields, such as equipment and building design, agriculture and the military have performed research in this area as they require knowledge of how often certain temperature thresholds are equaled or exceeded.

Previous research has encompassed techniques that strove to estimate temperature frequencies at any point along the cumulative temperature frequency curve to those that have focused solely on estimation within the tails of the distribution. Researchers have sought to explain the characteristics of a location's cumulative frequency distribution by association with combinations of both topographic and climatic variables, such as latitude, elevation, standard temperature means and extremes, air mass frequencies, and the moisture environment.

### Model development

A model has been developed that uses many of these associated climatic and topographic variables to assign stations to groups whose members possess common characteristics in their geographic and climatic attributes and in their cumulative temperature frequency distributions. Using discriminant analysis with two geographic and six climatic variables, 276 stations ranging from the Tropics to the Arctic have been assigned to groups on a monthly basis that reflect commonality in their temperature frequency distributions. Discriminant functions and curve-fitting equations also were generated.

When comparing the mean temperature frequency group curve to those of their constituent group members, performance was best in summer and poorest during the more thermally diverse winter season. During the summer, about 84 percent of all the stations had no differences that exceeded 2.0°C between their individual curves and the group mean curves at 19 separate frequency levels. When comparing individual station cumulative temperature frequency curves with the group mean curves during the summer months, more than 96 percent of all temperatures were within the established ±2.0°C tolerance. During the winter season, this value dropped to 65 percent of all stations having no values out of tolerance and 90 percent of all generated levels within tolerance. Annually, the model estimated more than 92.5 percent of all temperature levels within the tolerance criterion.

### Performance levels

Geographically, the model performed best for stations: at locations with low to moderate elevations; in regions with higher station densities; and during the warmer months of the year. Poorer model performance correlated well with: high latitude locations; high elevation sites; regions with extremely sparse station densities; and during the colder months of the year.

These models have been incorporated in a software package that will be implemented on the U.S. Army Topographic Engineering Center's Digital Topographic Support System. The software allows the military planner to select a station, a month and a temperature value, and then computes the average percentage of time that this temperature occurs. This capability will provide the military planner with a better assessment of the thermal environment of a location and allow an evaluation of the frequency of time that thermal conditions might prove to be a negative factor to equipment, personnel and planned operations. This model also will assist the materiel developer in assessing the thermal environment of potential deployment areas. A technical report on this research was prepared – "*An Empirical Method to Derive Hourly Temperature Frequencies for Locations Possessing Only Summarized Climate Information*" (TEC-0097). (Dr. Paul F. Krause is a geographer with the U.S. Army Topographic Engineering Center, CETEC-TR-G, Alexandria, VA 22315-3864, DSN 328-6840, 703-428-6840 or e-mail: pkrause@tec.army.mil)

# TOPOGRAPHIC SUPPORT CAPABILITY

## TEC provides support to verify and validate selected Mapping, Charting and Geodesy algorithms for potential Army Reuse Center users

**by Robert Atkins and Joni Jarrett**

Today, many basic Mapping, Charting and Geodesy (MC&G) algorithms (e.g., Line-of-Sight (LOS) and Mobility) are being incorporated into fielded systems that play key roles in the training of U.S. soldiers. A majority of these algorithms have been around since the 60s and 70s, and it is unfortunate that many of them have never gone through a formal verification and validation (V&V) procedure. This undeniable fact creates a requirement to ensure all MC&G algorithms in use by our soldiers and possibly our allies are reliable and used correctly. The U.S. Army Topographic Engineering Center (TEC) has taken on the project to V&V selected MC&G algorithms and make these algorithms accessible to potential users through the Army Reuse Center (ARC).

### Obstacles

There are three major hurdles that quickly come to mind that must be overcome in order for any Software Reuse/Reengineering effort to work. These obstacles that must be overcome are 1) Army Policy, 2) Technical Evaluation and 3) Marketing. Each of these categories has its unique problems.

***Army Policy*** - How can a process be put into place that ensures an optimal use of reusable code? The cost of using reusable code has been shown to reduce total development time and cost. Before any new development is started project/program managers have to be compelled to take advantage of mature software (i.e., V&V, limitations identified, interface defined, software documented). Additional training must be offered to help managers better delegate system resources to evaluate potential uses of developed software. It might look like things are getting done by developing new code from scratch, but that approach to the problem requires a testing phase, which is rarely done to completion.

***Technical Evaluation*** - The initial cost of conducting a full-scale technical evaluation of an algorithm is extremely expensive. The only way to recoup this cost is to make repeated use of the software in many applications. The technical evaluation phase consists of both the V&V efforts and the accreditation phase. The accreditation phase must be done by the end user to make sure that the software supports a specific application. This phase requires some initial up front cost but is inexpensive when compared to the V&V phase.

***Marketing*** - Advertising what is available is the major problem when dealing with reusable code. The Army has taken great strides in setting up the ARC and has assigned appropriate domain managers to evaluate any software added to the reuse library. TEC is the domain manager for the MC&G section of the ARC library. The joint community has the Modeling and Simulation Resource Repository (MSRR) in which the Master Environmental Library (MEL) is just a part of that project. Each of these libraries need as much exposure as possible to get the greatest return for the dollar.

### Project summary

Currently, TEC is involved in an effort to establish guidelines and evaluate procedures for testing widely used LOS algorithms (e.g., Digital Topographic Support System (DTSS), Masked Area Model, ModSAF, DYNTACS, Breshenham and DrawLand (a TEC-developed software package)).

***Background*** - Driven by hardware, data, and timing issues, several methods have evolved to model straight line geometry. However, each method has assumptions and limitations that reduce the accuracy of the results. Understanding and documenting these limitations is one of the primary goals in this project. Several factors have driven the varied LOS software development. The modeling and simulation's visualization community has derived a hardware-driven algorithm that works with triangular irregular and triangular regular networks (TIN, TRN). The analytical community has developed near-squared approaches to address timing requirements. Separate MC&G communities have developed varied interpolative approaches to minimize data limitations that support combat-specific model analysis.

***Verification and Validation*** - In its initial phase the project focuses on Optical LOS algorithms that deal with straight-line geometry and the determination and delineation of masked and unmasked areas. The first application selected for testing was a Masked Area LOS

algorithm. It was taken from the suite of models hosted on the TEC-fielded DTSS. Once the DTSS algorithm was identified, the effort proceeded to acquire existing information about the code and a series of elevation data bases for test purposes. V&V procedures for an algorithm requires that the existing code be:

- studied in-depth;
- installed on a testing platform;
- modified and/or corrected;
- compiled;
- evaluated for complexity and maintainability using a software testing tool;
- tested by executing a test plan on multiple data sets;
- statistically analyzed with highly-accurate field-collected reference data;
- and finally, assessed as to the level of algorithm efficiency, limitations, and appropriate applications.

Upon V&V completion, the algorithm with its ancillary documentation will be submitted to the MC&G repository at the ARC.

***Test Data*** - The test data used in this analysis consists of high-resolution gridded elevation data and high-precision field-collected visibility information over six study areas. These data sets are Fort Benning, Ga.; two sites at Fort Irwin, Calif; Twenty-Nine Palms, Calif.; Yuma Proving Grounds, Ariz.; and Yakima Firing Center, Wash. One-meter elevation grids exist for the Fort Benning and Twenty-Nine Palms sites. The other four areas all have a 5-meter resolution. Because the data are critical components for the testing process, a high level of effort was dedicated to ensuring the validity and the composition of each data set. To maintain a description of the data, a Metadata file for each of the 12 data areas was generated. The test data along with its respective Metadata will be placed on TEC's MEL. The MEL is a Defense Modeling and Simulation Office-sponsored distributed environmental data access system, which provides the framework for storing and accessing high-value data sets.

***Benefits/Products*** - The final product will be a tested algorithm available for the ARC to distribute to all Department of Defense (DOD) users along with documentation that includes an algorithm abstract, a test plan complete with test purpose and correct results, algorithm usage procedures, and algorithm limitations as concerns both software and data. The benefits from any software algorithm that has gone through a formal V&V are substantial. The development time to write the code has been eliminated for potential developers and integration costs are reduced drastically since documentation is available explaining all input

## V&V Test Plan (High-Level Summary)

**Verification Testing (all documented)**

| | |
|---|---|
| **1.0 Functional Testing (Black Box)** | **Parameter Extreme Points**<br>**Error Handling** |
| **2.0 Structural Testing (White Box)** | **Algorithm Correctness**<br>**Completeness Testing** |
| **3.0 Platform Testing** | **System Dependencies**<br>**Rounding/Truncation** |
| **4.0 Mathematical Correctness** | **Flat/Spherical/Ellipsoidal Earth**<br>**Interpolation** |
| **5.0 Data Sensitivity** | **Resolution**<br>**Accuracy** |

**Validation Testing (also documented)**

| | |
|---|---|
| **1.0 Masked/Unmasked Areas** | **Algorithm-Calculated Profiles**<br>**Field-Collected Visibility Data**<br>**Metadata**<br>***Statistical Analysis*** |

**TEC has taken on a project to verify and validate selected Mapping, Charting and Geodesy algorithms and make these algorithms accessible to potential users through the Army Reuse Center.**

## Products

**(1) Reusable software modules planned for distribution by the ARC:**

**DTSS Masked Area Model**
**ModSAF**
**DYNTACS**
**Breshenham**
**DrawLand**

**(2) Four Reuse Documents for each LOS algorithm:**

**Algorithm Abstract**
**Reuse Manual**
**Test Plan**
**User's Guide**

**TEC is involved in an effort to establish guidelines and evaluate procedures for testing widely used LOS algorithms.**

parameters and appropriate tests. Additionally, the life cycle maintenance for these algorithms has been demonstrably reduced.

The goal of this project is to increase the number of standardized, well-tested MC&G algorithms available from the ARC for DOD users. Major benefits of this effort are that users of these algorithms will have increased confidence in the results and the increased opportunity for interoperability across joint systems.

### Conclusions

TEC plans to continue the effort begun in this project and will expand upon the current work by evaluating several additional LOS algorithms/models. Candidate algorithms are ModSAF, DYNTACS, Breshenham, and DrawLand. For each additional algorithm, the DTSS Masked Area Model test plan will be used to compare the algorithm's results with field-surveyed ground truth. Each of the algorithms will be documented and all reuse documentation will be produced to ARC guidelines. Currently, TEC tests all MC&G modules that are submitted to the ARC. The ARC is on the internet, along with the MEL at the following address: arc_www.belvoir.army.mil and www-MEL.nrlmry.navy.mil.

### Future work

It is envisioned that this work will be expanded to look at additional LOS algorithms along with mobility and LOS-based Tactical Decision Aids (TDAs). This initial effort focused on V&V with respect to the correct usage of the LOS module (masked/unmasked) and documenting the interface. TDAs have to undergo a V&V process with respect to the intended purpose of the software (validation). Current candidates under consideration for this phase are the LOS TDAs used in the DTSS system. (Robert Atkins is a computer scientist at the U.S. Army Topographic Engineer Center, CETEC-GD-A, 7701 Telegraph Road, Alexandria, VA 22315-3864, DSN 328-6864, 703-428-6864, telefax 703-428-6991 or e: mail: ratkins@tec.army.mil. Joni Jarrett is a physical scientist at the U.S. Army Topographic Engineer Center, CETEC-TR-G, 7701 Telegraph Road, Alexandria, VA 22315-3864, DSN 328-6840, 703-428-6840, telefax 703-428-8176 or e-mail: jarrett@tec.army.mil)

## Researchers expand testing of U.S. Plastic Lumber's breakthrough railroad tie

**by Dana Finney**

Out on the broad plains of eastern Colorado, trains run day and night, 7 days a week, through snow and rain, heat and cold, putting years of wear on rails, ties and roadbeds in only a few months. Such continuous testing goes on year-round at the AAR Transportation Technology Center in Pueblo, Colo., but a new type of track component, being tested and manufactured by U.S. Plastic Lumber Corp. (NASDAQ Bulletin Board: ECPL), is getting special attention from researchers and interested railroad companies.

These tests are expected to further verify that a newly designed plastic composite railroad tie can provide good performance and durability, while also being more environmentally friendly than ties made from creosote-treated wood. The new railroad tie, made of recycled plastic and recycled fiberglass, has undergone testing on a smaller scale at the Colorado test tract, and has already seen limited field use by several railroads. The new testing program will replicate many years of typical use by railroad, in an effort to determine the ultimate life span of the product.

#### Manufacturing confidence

"We are very confident and enthusiastic about these new tests," says Mark S. Alsentzer, president and chief executive officer of U.S. Plastic Lumber Corp. The company's operating arm, Earth Care Products, has the worldwide distribution rights to market the new plastic composite railroad tie, and is developing plans for increased manufacturing capacity to produce the new product in large quantities.

"We are very confident these new tests will confirm the preliminary findings, which show that this product has the potential to save millions of dollars, while enhancing safety and contributing to environmental goals," Alsentzer says.

Dr. Tom Nosker of Rutgers University, who is working with Earth Care in the testing program, is handling patent applications for the new product. Other test sponsors include Norfolk Southern Railroad, Conrail and the U.S. Army Corps of Engineers' Construction Engineering Research Laboratories.

"This is very accelerated testing," Nosker said. Tests began last year already have subjected two individual plastic ties to 110 million gross tones (MGT) of traffic, he explained. The two ties already have outperformed the wooden ties adjacent to them, according to Nosker.

The new testing will involve an installation of 20 consecutive ties, which will be monitored and tested repeatedly to determine how well the ties maintain gage and resist wear and abrasion under heavy loads.

#### Longevity and value

"We aim to find out just how long these ties will last," he added. "How long they last is directly proportional to how valuable they are. That's what we all want to know."

Richard Lampo, a materials engineer with the Army Corps of Engineers' Research Laboratories, agrees that the potential of plastic composite railroad ties is significant.

"The first two ties were put in at the request of Conrail," Lampo notes, "and they report that the ties today look virtually the same as the day they were installed. I'm told that the adjacent wood ties have sustained considerable wear and damage."

Longer tie life is very important to the Army, which operates its own rail systems on bases worldwide. Although the total amount of track is less than 3,000 miles, it includes some 12,000 turnouts (switches), which require ties that are longer—and therefore, more expensive—than standard 8-foot ties. When ties are made from recycled plastic, however, these longer lengths cost about the same for each foot of length.

Even in standard lengths, however, Earth Care is committed to reducing manufacturing costs to the point where the recycled plastic ties are much more cost-effective than wooden ties, especially when the total replacement cost is considered, along with the cost of downtime of the track while ties are replaced.

#### Additional research

The Colorado tests are only part of the research that is underway, Lampo added. "Conrail also has installed plastic composite ties in their yard in Altoona, Pa., and those have been performing fine even in locations where standing water is a problem," he noted. "In October 1996, they decided to install two groups of three ties each on a 6-degree curve in the Philadelphia to Pittsburgh main line track . . . and again, they've had good success."

Alsentzer noted that in the United States alone, railroads replace more than 14 million ties each year. A

creosote-treated wooden ties useful life may be as short as 5 years under severe loadings or exposures. The recycled plastic composite ties, however, have an estimated useful life of 50 years or more regardless of conditions.

"Because of the performance and durability of the product, we are extremely optimistic about the potential market for plastic composite ties," Alsentzer said.

U.S. Plastic Lumber is a leading manufacturer of recycled plastic lumber products. In addition to railroad ties, its Earth Care subsidiary also produces raw plastic lumber stock in standard wood sizes, along with outdoor benches, picnic tables and trash receptacles. Earth Care operates three recycled plastic lumber manufacturing plants, with a combined capacity of approximately 15 million pounds per year. The company also operates an environmental recycling division in the Northeast, which has processed in excess of 700,00 tons of contaminated soil and construction debris.

For more information, contact Mark S. Alsentzer, president, at 888-85-EARTH or 561-394-3511; or at http://www.ecpl.com. (Dana Finney is the chief of public affairs at the U.S. Army Construction Engineering Research Laboratories, Public Affairs Office, P.O. Box 9005, Champaign, IL 61826-9005, 217-373-6714.)

## ITEM OF INTEREST

### Abraham Anson, former ETL/TEC employee receives ASPRS 1997 Fellow Award

Abraham Anson, formerly a member of the U.S. Army Engineer Topographic Laboratories (ETL), now the U.S. Army Topographic Engineering Center, received the American Society for Photogrammetry and Remote Sensing (ASPRS) 1997 Fellow Award. He was cited for his unselfish contributions to the sciences and the society as associate editor for both the *Manual of Color Aerial Photography*, and the 1st Edition of the *Manual of Remote Sensing*. He also was recognized as the program chairman and editor of the proceedings of the Aerial Photo workshop for the plant sciences, non-topographic photogrammetry, a contributor of the *History of Photogrammetry in Neblette's Handbook of Photography and Reprography*, as well as many other key literary contributions.

Similarly, he has many noteworthy early contributions, which include examining the impact of supersonic air platforms in aerial photo acquisitions, the development of the Automatic Mosaicker, an extensive study of the language of color, comparing the information content of black and white aerial photography with color and color infrared, the development of a multiband camera, as well as a camera for the Apollo moon landing, and others.

# CONFERENCES

## XXI International Congress on Surveyors (FIG '98) set for July 19-26, 1998

The XXI International Congress on Surveyors (FIG '98) will take place in Brighton on the south coast of England, July 19-26, 1998. The conference will address all aspects of the surveying of land and marine resources, and will reflect both technical and commercial facets of the property and construction industry.

There will be more than 60 technical poster and special sessions covering the surveying profession, from professional practice and education through surveying, mapping and land information systems to land, property and construction management, spatial planning and valuation.

For more information, contact FIG '98, RICS Conferences and Training, 4 Buckingham Gate, London SWIE 6JR, telephone +44 (0) 171 393 4960 or telefax +44 (0) 1171 872 0045.

## Fourth International Symposium on Environmental Geotechnology and Global Sustainable Development scheduled for Aug. 9-12, 1998

The Fourth International Symposium on Environmental Geotechnology and Global Sustainable Development is scheduled to be held Aug. 9-12, 1998 in Boston, Mass.

Exponential growth in population and rapid pace of economic development have synergistically created the need for advances in environmental control techniques. Geoenvironmental research advances, technological innovation, appropriate technology transfer and indigenous technology development are important elements of sustainable development. This symposium is appropriately scheduled to address relevant technical and policy issues close to the beginning of the 21st century.

Sponsors of the Symposium are the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory, New England Water Environment Association, Battelle Pacific Northwest Laboratory and National Institute for Standards and Technology. The host for the symposium is the Center for Environmental Engineering, Science and Technology, University of Massachusetts, Lowell, Mass.

For more information, contact Dr. Hilary I. Inyang, Dupont Young Professor and Director, University of Massachusetts, Center for Environmental Engineering, Science and Technology, James B. Francis College of Engineering, One University Avenue, Lowell, MA 01854, 508-934-2285, telefax 508-934-3092 or email: inyangh@woods.uml.edu.

## Third Tri-Service Environmental Technology Workshop set for Aug. 18-20, 1998

The U.S. Army Environmental Center, Aberdeen Proving Ground, Md., is hosting the Third Tri-Service Environmental Technology Workshop Aug. 18-20, 1998 in San Diego, Calif.

The workshop will provide a training forum for technical exchange and interaction on Environmental Technology strategies, initiatives, demonstrations and products. Army, Navy, Air Force and Department of Defense personnel, as well as other federal agencies, contractors, academia and industry are invited to attend.

For more information, contact Sonya L. Herrin, Science and Technology Corp. Inquires may be made by telephone at 757-766-5858, telefax 757-865-8721 or e-mail: herrin@stcnet.com. Additional information may be obtained through the web site at http://www.stcnet.com.meetings/etw98.html.

## Third NATO-IRIS Joint Symposium to be held Oct. 19-23, 1998

The Third NATO-Infrared Information Symposia (IRIS) Joint Symposium will be held Oct. 19-23, 1998 in Quebec City, Canada. The symposium is sponsored by IRIS and the NATO RTO Sensors and Electronics Technologies (SET) Panel. This classified conference will address military and security applications of all sensing technologies.

With its theme of "Innovation in Military and Security Sensing," the symposium will provide scientists, engineers and managers from government, industry and academia an opportunity to learn about the broad range of sensing requirements, programs and technology developments within the overall NATO framework.

The symposium will be held at the national SECRET level. Each attendee must hold a SECRET clearance issued by a NATO SET member country. Attendance will be open only to residents of the NATO SET Panel participating countries.

For more information, contact ERIM International Inc., P.O. Box 134008, Ann Arbor, MI 48113-4008, 313-994-1200, Ext. 2881, or e-mail: iris@erim-int.com.

# ARO CONTRACTS

The Army Research Office (ARO) is the major agency for support of extramural 6.1 research within the Army. ARO is organized into divisions on a disciplinary basis. The Environmental Sciences Branch has responsibility for support of environmental research and is itself divided into an Atmospheric Sciences Section and a Terrestrial Sciences Section. Funded projects are the result of unsolicited proposals which have survived a rigorous peer review by Army and non-Army referees, and have demonstrated relevance to Army problems. The Scientific Liaison (SL) and Scientific Cognizance (SC) mechanisms allow Army laboratory scientists to request either designation for particular research projects. They receive periodic progress reports, and reprints enabling them to track the progress to the research. Listings of currently active projects are available.

***Atmospheric Sciences: New Starts at ARO, FY97 Since Last Issue***:

"Tropospheric Lidar: Development of Techniques, and Practical Measurements"
Principal Investigator: Thomas Wilkerson, Utah State University

"Collaborative Research: Lagrangian Modeling of Dispersion in Planetary Boundary Layer"
Principal Investigator: Peter Sullivan, National Center for Atmospheric Research

"Collaborative Research: Lagrangian Modeling of Dispersion in Planetary Boundary Layer"
Principal Investigator: Jeffrey Weil, University of Colorado

"Improved Subgrid-Scale Modeling in the Atmospheric Surface Layer"
Principal Investigator: John Wyngard, The Pennsylvania State University

"Equipment to Construct a FMCW Radar to Study Atmospheric Boundary Layer"
Principal Investigator: Robert McIntosh, University of Massachusetts

"Augmented Sensitivity and Dynamic Range for ARO-DURIP Lidar"
Principal Investigator: Thomas Wilkerson, Utah State University

"Equipment to Migrate the Turbulent Eddy Profiler Data Acquisition System to VXI"
Principal Investigator: Robert McIntosh, University of Massachusetts

"High Resolution Rainfall Observing System for Support of Remote Sensing Studies"
Principal Investigator: Witold Krajewski, University of Iowa

"Development of a Multi-Sensor System for Measurement of 4D Atmospheric Boundary Layer Structures"
Principal Investigator: Kevin Knupp, University of Alabama, Huntsville

"Construction of an Advanced Wind Measuring LIDAR"
Principal Investigator: William Eichenger, University of Iowa

"Upgrade of a Portable Mini-LIDAR for the Study of Nocturnal Atmospheric Boundary Layer Structures"
Principal Investigator: David Miller, University of Connecticut

"Detection of Biological and Non-Biological Aerosols via Fluorescence Spectrum and Surfactant on Droplets Via Harmonic Generation"
Principal Investigator: Richard Chang, Yale University

"Detection of Biological Airborne Particles with UV-Excited Fluorescence Spectra"
Principal Investigator: Richard Chang, Yale University

"On Experimental Verification of the Modern Theory of Sound Propagation in the Turbulent Atmosphere"
Principal Investigator: Vladimir Ostashev, New Mexico State University

"Study of the Atmospheric Boundary Layer using the Turbulent Eddy Profiler"
Principal Investigator: Robert McIntosh, University of Massachusetts

"Turbulent Patched in Stratified Shear Flows"
Principal Investigator: Harindra Fernando, Arizona State University

"International Workshop on Turbulence and Diffusion in the Stable Planetary Boundary Layer"
Principal Investigator: Carmen Nappo, National Oceanic and Atmospheric Administration

***Terrestrial Sciences: New Starts at ARO, FY97 Since Last Issue*:**

"The Compressive Failure of Large Block of Columnar Ice Containing Cracks"
Principal Investigator: Erland Shulson, Dartmouth College

"Workshop on New Research Directions in Surficial Processes and Landscape Dynamics within Desert Environments"
Principal Investigator: Stephan Wells, Desert Research Institute

"Field Studies of Nearshore Morphology"
Principal Investigator: Thomas Drake, North Carolina State University

"A Large Deformation, Finite Element Analysis of Soil-tire Interaction Based on the Contact Mechanics Theory of Rolling and/or Sliding Bodies"
Principal Investigator: Antionette Tordesillas, University of Melbourne

"Model Structure Error and Model Complexity in Groundwater Modeling"
Principal Investigator: William Yeh, University of California, Los Angeles

"Acquisition of Instrumentation for Strengthening the Environmental Science Graduate Program at UOG"
Principal Investigator: Peter Motavalli, University of Guam

"Strengthening Science Infrastructure at D-Q University"
Principal Investigator: Suresh Tiwari, D-Q University

"Instrumentation Improvement on Environmental Sciences to Strengthen Undergraduate Laboratory Instruction"
Principal Investigator: Gabriel Infante, Pontifical Catholic University of Puerto Rico

"Ice Adhesion"
Principal Investigator: Victor Petreno, Dartmouth College

"Augmentation Award for Unsaturated Soil Hydraulic Parameter Studies"
Principal Investigator: Molly Gribb, University of South Carolina

"Student Support for Elecyrochromic Polymer-Based Systems"
Principal Investigator: John Ferraris, University of Texas at Dallas

"Supplemental Student Support for Ascender II: Knowledge-Directed Image Understanding for Site Reconstruction"
Principal Investigator: Allen Hanson, University of Massachusetts

"Impact of Wheeled Vehicle Maneuvering on Soils of the Chihuahuan Desert"
Principal Investigator: William Mackay, University of Texas at El Paso

"Development of Efficient and Accurate Models of Groundwater Flow and Transport"
Principal Investigator: Thomas Russell, University of Colorado, Denver

"International Workshop on Characterization and Measurement of the Hydraulic Properties of Unsaturated Porous Media"
Principal Investigator: M. Th Van Genuchten, University of California, Riverside

"Seismotechtonics of the Middle East and North Africa: Developing a Database in Support of CTBT Verification"
Principal Investigator: Muawia Barazangi, Cornell University

"Fourth International Conference on Case Histories in Geotechnical Engineering"
Principal Investigator: Shamsher Prakash, University of Missouri at Rolla

(Dr. Walter Bach Jr., U.S. Army Research Office, P.O. Box 12211, Engineering and Environmental Sciences Division, AMXRO-EN, Research Triangle Park, NC 27709-2211, DSN 832-4362, 919-549-4360 or telefax 919-549-4310)

# EDITORIAL BOARD

## Points of Contact for *Army Battlefield Environment* Editorial Board

**Editor's note:** Organizations interested in submitting articles and/or photos for publication in *Army Battlefield Environment* can contact one of the board members listed below for more information.



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William E. Roper

WILLIAM E. ROPER, Ph.D., PE
Director